GUIDED MISSILEMAN

3 & 2

Prepared by

U.S. **BUREAU OF NAVAL PERSONNEL**

NAVY TRAINING COURSES

NAVPERS 10153

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ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E–2 or 8 mos. total service.	6 mos. as E–3 or 14 mos. total service.	12 mos. as E–4.	12 mos. as E–5; total service at least 36 mos.	36 mos. as E–6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E–3 and all PO advancements.				
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

PREFACE

This Navy Training Course was written to serve as an aid for enlisted men of the U. S. Navy and the U. S. Naval Reserve who are preparing for advancement to the rate of Guided Missileman 3 or 2. As noted in the Reading List and throughout the text, comprehension of the technical material contained in this course requires some basic knowledge in the fields of hand tool skills, hydraulics, electricity, and electronics. If this knowledge is not already possessed, it can be acquired by studying the four basic Navy Training Courses which are listed in the Reading List. The use of the USAFI material in the Reading List also will enable the striker to acquire a better background for further study in the field of guided missiles.

This course provides information concerning the history, aerodynamics, propulsion, guidance and control, handling, and testing of guided missiles. An introduction to missile telemetering is presented. Material on missile safety precautions and first aid procedures is included in the last chapter.

As one of the NAVY TRAINING COURSES, this text was prepared by the Training Division of the Bureau of Naval Personnel. Technical assistance was received from the Bureau of Ordnance and from the Applied Physics Laboratory of Johns Hopkins University at Silver Spring, Maryland. The assistance of the United States Air Force in providing certain technical illustrations is appreciated.

READING LIST

NAVY TRAINING COURSES

Basic Hand Tool Skills, NavPers 10085
Basic Electricity, NavPers 10086
Basic Electronics, NavPers 10087
Basic Hydraulics, NavPers 16193

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to the GS rating is as follows:

SELF-TEACHING

Number	Title
MC 290	*Physics I*
MB 781	*Fundamentals of Electricity*

CORRESPONDENCE

CC 290	*Physics I*
CB 781	*Fundamentals of Electricity*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more or if they have been on active duty for a period of 120 days or more regardless of the time specified in the active duty orders."

CONTENTS

GUIDED MISSILEMAN

3 & 2

CHAPTER 1

THE GUIDED MISSILEMAN

DUTIES AND RESPONSIBILITIES

Guided Missilemen handle, maintain, and repair surface launched guided missiles and associated test equipment. Their routine duties are both military and professional. The military duties are similar to those in other Navy ratings; the professional duties are determined largely by the nature and characteristics of the missiles with which they work.

Ship launched guided missiles, whether in surface-to-air, surface-to-surface or surface-to-underwater versions, are complex and intricate devices. Fired from surface vessels, or from submarines, typical missiles fly at near sonic or supersonic speeds. They are guided to the target by electronic systems such as radar or radio or by detectors of infrared radiation. The missiles are controlled in flight by complex systems containing gyroscopes; electrical systems; and electronic, hydraulic, and pneumatic devices. They are usually propelled by rocket motors or by some other form of jet propulsion; and they carry explosive warheads and often proximity fuzes. In view of the many systems which are coordinated in the tactical guided missile, it is necessary that the technicians who handle and maintain the weapon be highly trained specialists. Their work demands wide ranges of technical knowledge in several hitherto unrelated fields; and their routine duties involve many specialized skills.

The Guided Missileman rating (like all other Navy ratings) is a group of jobs which requires essentially the same

aptitudes, training, experience, skills, and abilities. In these jobs, Guided Missilemen work with all the internal components of surface-launched guided missiles except propulsion systems and ordnance devices. They employ and service many kinds of test instruments and telemetering equipment. They train other missilemen in the duties of the rating. They supervise missile handling and maintenance operations and perform the clerical and administrative duties required in these operations.

As in other Navy ratings, that of Guided Missilemen contains four rates: GS3, GS2, GS1, and GSC. The missileman's rate indicates his pay grade and also the level of his aptitude, experience, knowledge, skill, and responsibility. Advancement in the rating is dependent on meeting certain military and professional requirements which are listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). The professional qualifications for GS3 and GS2 form the basis of this text, which is intended as a study aid for personnel preparing for advancement to these rates. These qualifications, together with those required for advancement to GS1 and GSC, can be found in Appendix I of this course. These qualifications are subject to change; the current revision of NavPers 18068 should be consulted for the latest information.

The nature of the duties of the Guided Missileman and the types of tasks performed by him are indicated by the Navy Enlisted Classification number assigned to him. Guided Missilemen are given NEC's code ranging from GS 1300 to 1399. These code-numbers highlight the specialties which he may acquire during the course of his Navy career. The duties associated with the specialty are the same for all, that is, the Guided Missileman assembles, maintains, and repairs components associated with the internal guidance and control of missiles; makes pre-assembly tests of components, adjusting and replacing faulty parts; assembles components; tests assembled missiles; disassembles, adjusts, or replaces faulty components; reassembles and tests mis-

siles; makes preflight tests of completely assembled missiles to determine readiness for launching; employs special and standard test equipment; calibrates equipment and components assigned for field calibration; repairs, adjusts and calibrates special missile test equipment; maintains, repairs, and calibrates telemetering equipment. Specific codes are assigned for personnel specializing in either the *Regulus*, *Talos* or *Terrier* missile.

Guided Missileman Billets

Billets for Guided Missileman are established at naval depots, at air stations, aboard surface ships (cruisers, aircraft carriers and destroyers), aboard submarines, at guided missile units, guided missile service units and research and development sites.

At Navy ammunition depots Guided Missilemen receive missiles from the manufacturer, store them, and assist in the processes of distribution to the Fleet. These support facilities provide services for assembly and disassembly, testing and maintenance, and repair and major overhaul of guided missiles. In performing these services the Guided Missileman is concerned with all the components of the missile with the exception of the propulsion system and warhead.

Shipboard missile personnel receive supplies of missiles from the depots. They complete maintenance checks on the entire missile and its components. Missile personnel replace faulty sections, replace defective electronic packages and make various adjustments to the systems. They make tests to determine the readiness of the missile for use, maintain and repair test equipment, and service the electrical and electronic units required in the operational use of the weapon.

In training billets Guided Missilemen petty officers serve as instructors in Naval Guided Missiles Schools in which personnel are trained in the operation and maintenance of specific missiles. The instructors are carefully chosen from

personnel experienced in missile operations. They conduct classes in many of the phases of guided missile theory and practice, including such subjects as fundamentals of electricity and electronics, essentials of gyroscopes, missile motors, and servomechanisms. They instruct trainees in the authorized procedures for making operational and maintenance tests of specific missiles, and in the functions and operation of standard and specialized test equipment.

Guided missile units are assigned to Naval Test Centers to assist in the work of testing and evaluating new guided missiles. Personnel of these missile units receive specialized instruction in the procedures of handling, preparing, and maintaining new weapons and learn to service and operate the equipment associated with them. The development project to which the missile unit may be assigned also assists in determining the suitability of new missiles for introduction into the Fleet, in working out procedures for training personnel in their use, and in rendering many other services to various naval activities engaged in missile test and development.

Safety

An important part of the professional knowledge required of missilemen is that which pertains to safety. He is required to know the authorized methods of resuscitating victims of electric shock and of treating electrical burns. He must know and observe the safety precautions prescribed when working near high voltages, and must understand the hazards present in electrical and electronic equipment. He is required to know and to observe safety measures relating to ordnance devices such as rocket motors, high explosive warheads, fuzes, and igniters. Some of his work may be done near aircraft particularly if he works with *Regulus*; hence he must understand and practice the precautions appropriate for this type of work as well as those pertaining to jet engines and various mechanical devices. In addition, he is expected to be familiar with the hazards of hydraulic

and pneumatic systems and to use proper safety measures when working with them.

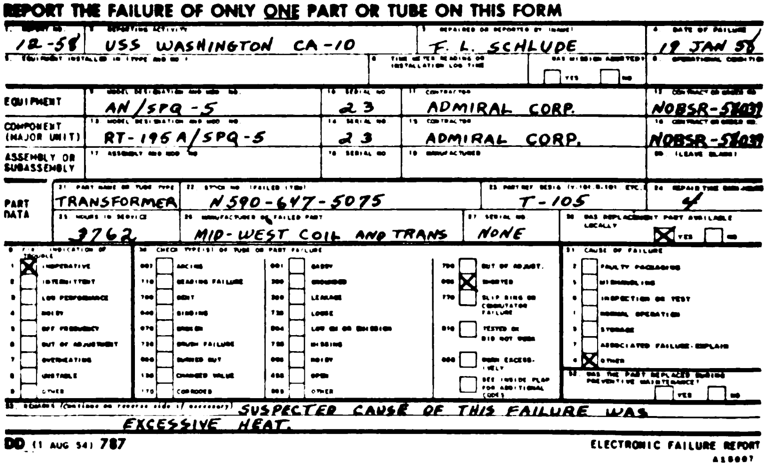
Clerical Duties

The clerical duties of guided missile technicians include the preparation of various records and reports which are required in missile activities. These duties include maintaining missile logs, recording test data, keeping equipment histories, and the preparation of failure reports, job orders, and work requisitions.

EQUIPMENT HISTORIES AND FAILURE REPORTS.—Guided missilemen maintain equipment histories and make failure reports which are required in routine maintenance and repair of electrical and electronic equipment such as test sets, radar installations, and radio systems. The facts relating to equipment failures are recorded on electronic equipment history cards. A card is kept for each such device or unit and accompanies it during its useful life. Each history card, when properly filled out, contains information such as the type designation and serial number of the unit, the contractor, the contract number, the date of the original installation, and the installing activity. In addition to these data, an entry is made each time a failure of the equipment occurs so that the past repair history is available at any time. The information provided by the history card is used when making reports of the failures of single parts of the unit such as tubes, resistors, and capacitors.

Reports of parts failures are made by means of standard report forms, an example of which is shown in figure 1–1. Parts failures in electrical equipment as well as those in electronic units are reported on this form.

MISSILE LOGS.—Each missile delivered by the manufacturer is accompanied by logbooks which are used to keep an accurate history of the weapon from the time of delivery to the time it is expended. Upon receipt of the missile the logs contain entries made at the factory showing the results of the manufacturer's final system test. Before acceptance


REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

12-58 USS WASHINGTON CA-10 F. L. SCHLUDE 19 JAN 58

EQUIPMENT AN/SPQ-5 23 ADMIRAL CORP. NOBSR-58039

COMPONENT (MAJOR UNIT) RT-195A/SPQ-5 23 ADMIRAL CORP. NOBSR-58039

ASSEMBLY OR SUBASSEMBLY

PART DATA TRANSFORMER N590-647-5075 T-105 4

3762 MID-WEST COIL AND TRANS NONE

SUSPECTED CAUSE OF THIS FAILURE WAS EXCESSIVE HEAT.

DD (1 AUG 54) 787 ELECTRONIC FAILURE REPORT

Figure 1-1.—Electronic failure report.

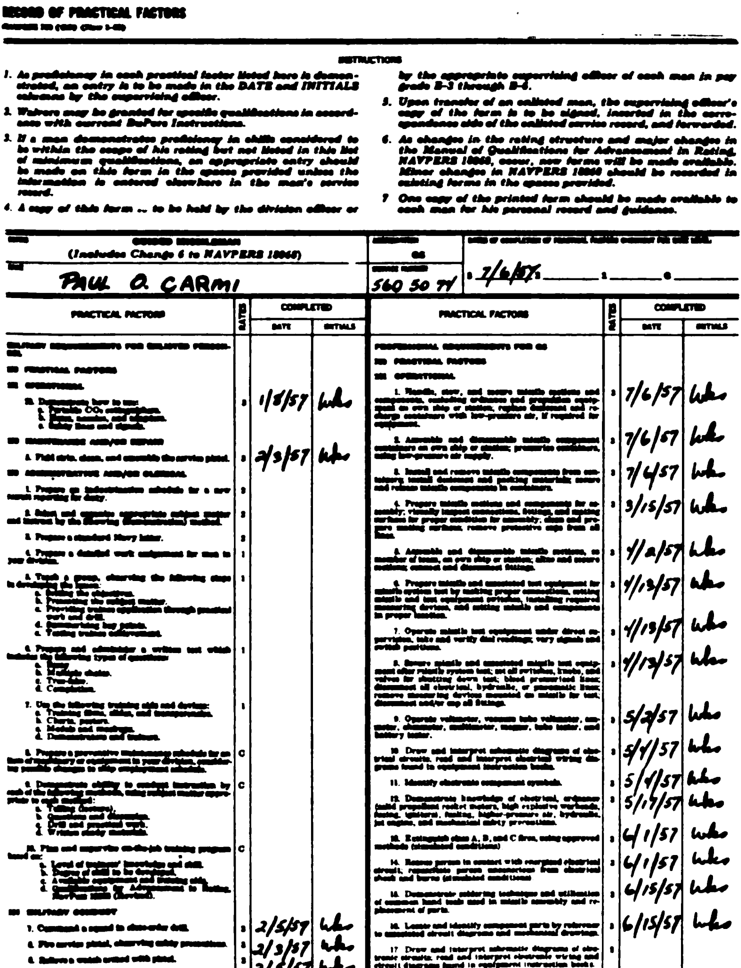
of the weapon, an inspection is made by authorized Navy personnel to verify the log entries, and subsequent entries are made to record the further history of the missile. These entries give the results of field tests, preflight checks, operating times of the component parts, equipment failures during test, and any modifications made to the missile. In the case of modifications, the corresponding entries are made in the component parts section of the log. This section contains a list of all the major units which make up the missile together with the serial number of each unit. With each replacement, an entry is made showing the serial number of the new unit and the date of its installation.

Studying for Advancement in Rating

Among the essential requirements for advancement in the Guided Missileman rating are demonstration of proficiency in the appropriate practical factors and successful completion of the prescribed Navy Training Course, or Courses. The first requisite is met by use of a special form; the second is accomplished under the guidance of an authorized bibliography which specifies the required courses and

related publications. Consider first the use of the practical-factor record.

Record of Practical Factors.—Since 8 February 1956, the use of the standard form NavPers 760, Record of Practical Factors (fig. 1–2) has been prescribed for all active


RECORD OF PRACTICAL FACTORS

INSTRUCTIONS

1. As proficiency in each practical factor listed here is demonstrated, an entry is to be made in the DATE and INITIALS columns by the supervising officer.
2. Waivers may be granted for specific qualifications in accordance with current BuPers Instructions.
3. If a man demonstrates proficiency in skills considered to be within the scope of his rating but not listed in this list of minimum qualifications, an appropriate entry should be made on this form in the space provided unless the information is entered elsewhere in the man's service record.
4. A copy of this form ... to be held by the division officer or by the appropriate supervising officer of each man in pay grade E-3 through E-6.
5. Upon transfer of an enlisted man, the supervising officer's copy of this form is to be signed, inserted in the correspondence side of the enlisted service record, and forwarded.
6. As changes in the rating structure and major changes in the Manual of Qualifications for Advancement in Rating, NAVPERS 18068, occur, new forms will be made available. Minor changes in NAVPERS 18068 should be recorded in existing forms in the space provided.
7. One copy of the printed form should be made available to each man for his personal record and guidance.

(Includes Change 6 to NAVPERS 18068)

PAUL A. CARMI

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Figure 1–2.—Sample NavPers 760.

duty personnel. A special form is available for each rating and consists principally of a listing of the military and professional practical-factor qualifications which are prerequisites for advancement. In addition to the pertinent factors, the form provides space for the supervising officer to date and initial the completion of each factor. It also contains a space for making minor changes in the factors and gives directions for forwarding the information from one duty station to another.

The record is kept, usually by the division officer, in a way that will facilitate the marking of the form as the practical factors are demonstrated by the trainee. When the latter is transferred, his Record of Practical Factors is signed, inserted in the correspondence side of his Enlisted Service Record, and forwarded to his next duty station. In this way the record is kept up to date and is employed on a continuing basis as the man progresses in his rating.

The forms are obtained through regular supply channels. When ordering them, use the designator NavPers 760 with the appropriate rating abbreviation following the number. For example, NavPers 760 (GS) should be ordered for use by the Guided Missileman.

BIBLIOGRAPHY OF TRAINING COURSES AND PUBLICATIONS.—A source of essential information for those preparing for advancement in the GS, as well as in other ratings, is provided by the bibliography entitled *Training Publications for Advancement in Rating*, NavPers 10052. This booklet is issued annually by the Chief of Naval Personnel. It lists Navy Training Courses and other publications required or recommended in the study for advancement in each of the various rates and ratings. The required Navy Training Courses are indicated in the bibliography by asterisks. Those so marked must be completed by the trainee at a given rate level before he is eligible to take the corresponding advancement examination. In addition, basic courses, general courses, and in some cases, study guides, are listed which provide valuable sources of supplementary information.

When using the bibliography, it must be realized, as indicated in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, that all higher pay grades listed in the booklet may be held responsible for the materials in the publications listed for the lower rates of the particular rating. Since in many instances only pertinent sections of publications are specified in NavPers 10052, for the most intelligent use of this booklet will be made by concurrent reference to the *Qualifications Manual* for the rating concerned. Here again, it is necessary to make certain that the latest change of the "Quals" Manual is being used.

HOW TO STUDY NAVY TRAINING COURSES.—Here is a method of study recommended for use with the course, *Guided Missileman, 3 & 2*, as well as with other courses and publications listed in NavPers 10052. This procedure contains some of the ways that have been found most effective by trainees studying Navy Training Courses for advancement. It is outlined in the following paragraphs, which are quoted from the *Navy Training Bulletin* (June–July 1957):

Start by reading the preface, table of contents, and index. Then thumb through the entire book, looking at the illustrations and reading bits here and there as your eyes fall on something interesting. This browsing will show you how the book is organized and the subject matter it covers.

Next, preread the entire course. Do this to learn the relationship of parts and chapters to the whole of the rating covered in this course. Read the introduction to each chapter. Then read the headings and subheadings and finally the summary, if the chapter contains one. Ask yourself such questions as: what do I already know about this particular topic? How are these topics interrelated? What am I expected to know about this process or technique?

Learn the qualifications for advancment in your rating (in the appendix). You are studying the NTC in order to meet these "Quals."

Check the Chapter Study Guide for the chapters most pertinent to the rate you seek. This is especially important for those ratings in which Selected Emergency Service Rates have been activated.

These preliminary steps orient you and help you plan your study, put you in a better position to draw on personal experience and to relate your past experience to the new material.

After this preliminary work you are ready to fill in the details by intensive study of the chapters, sections and subsections. What

you can cover during a study session depends on (1) the difficulty of the material; (2) what you already know about the topic; and (3) your skill as a reader. At any rate, for each study session plan to master a predetermined unit of material: an entire chapter or a major section of a chapter.

Use the PREREADING system with each section and paragraph. Skim the introduction, headings, first and last sentences of each paragraph, and all summarizing statements. As you preread, think up questions about the material. Write down these questions for future reference. Another useful technique is to make an outline during prereading, filling in the details later. When you have finished prereading, think about what you have learned thus far. Ask yourself such questions as: What main ideas are presented? What details must I look for?

Next, read the entire chapter or section completely and carefully. As you read be on the lookout for the questions you have thought about or the details of your outline. Relate the part to the whole. Relate your previous knowledge and background experience to the discussion. Identify yourself with the situations, processess, and techniques; visualize yourself doing the things that are described.

Recite what you have learned. This is the proof of understanding. Look at the questions you wrote down during prereading. Do you know the answers? Can you answer the questions in the quiz at the end of the chapter? Try to master the material you are studying before proceeding to a new portion of the text.

In this first chapter the duties of the Guided Missileman have been described. It has been pointed out that the Guided Missileman is primarily responsible for the maintenance and repair of the missiles with which he is concerned, together with the test equipment for each type missile. This chapter has also discussed the various billets open to personnel who hold or will hold the rating, Guided Missileman.

In connection with the methods of study prescribed for this course, it is necessary that the basic texts outlined in the reading list be used extensively. It is recommended that they be mastered prior to the study of this text, since a large part of the Qualifications for Advancement in these two rates are satisfied by the books included in the reading list.

Chapter 2 concerns itself with the guided missile, its development and its use as a military weapon.

The chapters which follow cover the fundamentals of missiles and their components. No attempt is made to point out specific missiles, and the components and systems described may be applicable to surface-launched, subsurface or air launched missiles. All, however, are associated with missiles and are fundamentals which a Missileman should know.

QUIZ

1. The routine duties of a Guided Missileman can be divided into two categories: MILITARY duties which are similar to those in other ratings and -------- duties which are determined largely by the nature and characteristics of the missiles with which they work.
2. Where can the requirements for advancement in the Guided Missileman rating be found?
3. What are the speciality codes called which are assigned to Guided Missilemen who have special skills with regard to specific missiles?
4. Guided Missileman billets exist aboard
   a. surface ships and submarines
   b. research and development sites
   c. guided missile service units
   d. all of the above
5. When a part such as a tube or capacitor of an electronic device fails, which of the following reports should be made to the Bureau of Ships?
   a. Electronic failure report
   b. Electronic history report
   c. Electronic status report
   d. No report is required for individual part failures.
6. Name four common entries which are made in missile logs.
7. A check-off list of practical factors for advancement in the Guided Missileman rating should be maintained on which of the following forms?
   a. NavPers 18068 (Revised)
   b. NavPers 760 (GS)
   c. NavPers 760 (PF)
   d. special form made up by own ship or station
8. In preparing for examination for advancement in rating it should be remembered that
   a. all qualifications will be covered by the appropriate Navy Training Course.
   b. NavPers 10052 should be consulted to learn of all required study material.
   c. Navy Training Courses are available for study on a voluntary basis.
   d. the examination will include only professional subjects; military requirements are covered by practical factors.

CHAPTER 2

INTRODUCTION TO GUIDED MISSILES

As a result of man's ingenuity the pace of modern warfare has been accelerated to the point where concepts of time and space must be revised. Weapons have been evolved from the simple hand thrown rock to those which travel at velocities in excess of the speed of sound. The earth has become a very small place and the protection previously provided by distance between combatants is no longer a major defensive factor. As a result of supersonic velocities, the time allowed to solve the counter attack problem does not permit human computation or mechanical resolution. Therefore the defense against enemy supersonic aircraft or missiles is a guided missile of our own, employing electronic computers and/or suitable effective countermeasure technique. Further, offensive operations, to be effective, must be carried out with weapons superior to those of the enemy. Our missiles must be able to destroy an attacker at a range beyond the lethal range of his weapons.

A guided missile may be defined as "An unmanned vehicle, designed as a weapon, which travels above the earth's surface along a course or trajectory that can be altered by a mechanism within the vehicle itself; this vehicle destroys itself in carrying out its mission." A guided missile usually contains all or most of the following items: (a) propulsion system, (b) guidance and control system, (c) warhead, (d) fuze, and (e) aerodynamic configuration and surfaces.

Guided missiles are being developed to overcome the limitations of "conventional" weapons. These conventional weapons have reached a point in engineering design where only a small improvement necessitates tremendous cost and effort. The improvements sought in the process of designing new weapons are (a) increasing the range from the point of release to the target, (b) decreasing the susceptibility to countermeasures and (c) increasing the destructive effect by either improving the accuracy or by carrying a larger destructive load. Each of these objectives has been satisfied to a degree by the guided missile. The necessity for and the concept or general idea of the guided missile have been covered. Let us now take a look at the evolution of the guided missile and how it fulfills the objectives described above.

DEVELOPMENT OF GUIDED MISSILES FOR WARFARE

Origin

The evolution of the guided missile as a military weapon began with rockets, which were first used by the Chinese against the Tartars in the Battle of Pien King in 1232. The British employed military rockets against the French in 1806, and again during the War of 1812. Great advances in the science of rocketry were made in the first part of the 20th century by an American, Dr. R. H. Goddard. One of his most notable achievements was the development of the mathematical theory of rocket propulsion and rocket flight, on which military and experimental calculations are now based.

The study of the rocket, the forerunner of guided missiles, brought about the realization that some form of guidance would be necessary if the potentialities of high speed and great range were to be used profitably. Even before the achievements of Dr. Goddard, steps had been taken to develop guided missiles. During the Civil War the torpedo was developed; it is now considered as the first missile which

used the preset guidance technique. At the outbreak of World War I torpedoes had been highly developed, and they were extremely effective during that war.

The use of airplanes as military weapons during World War I brought about the idea of remotely controlled aircraft that could be pilotless. An American, Charles F. Kettering, designed a pilotless aerial torpedo which, although not remotely controlled, made a successful stabilized flight in October 1919. The first such aircraft was a radio-controlled model airplane which was successfully flown about 1935. Drone planes were the first remotely controlled vehicles used by our Army and Navy.

German Development

The Germans accepted the airborne guided missile as a military weapon about ten years before World War II. During World War I they considered the possibility of improving bombing accuracy by using electric signals sent over fine wire to guide a bomb as it fell. In 1933 the German Army initiated a study of rockets and guided missiles; and in 1936 a research and development center was established at Peenemunde. A great many scientists were assigned to guided missile projects with the intention of producing a complete series of guided missiles to cover every field of defensive and offensive warfare.

Contracts were made with private firms, German universities, and technical schools for the development of rockets and guided missiles. Theoretical studies were undertaken, and considerable development of surface-to-surface weapons was completed. Guidance systems for surface-to-air weapons were not very successful, however, so in 1943 the 48 different antiaircraft missiles under development were consolidated into 12 weapons. The Germans attempted to carry these through to immediate development for operational use. At the end of World War II they were still working frantically to produce a surface-to-air guided missile with a speed of 300 miles per hour and a ceiling of about 50,000 feet for use against Allied bombers.

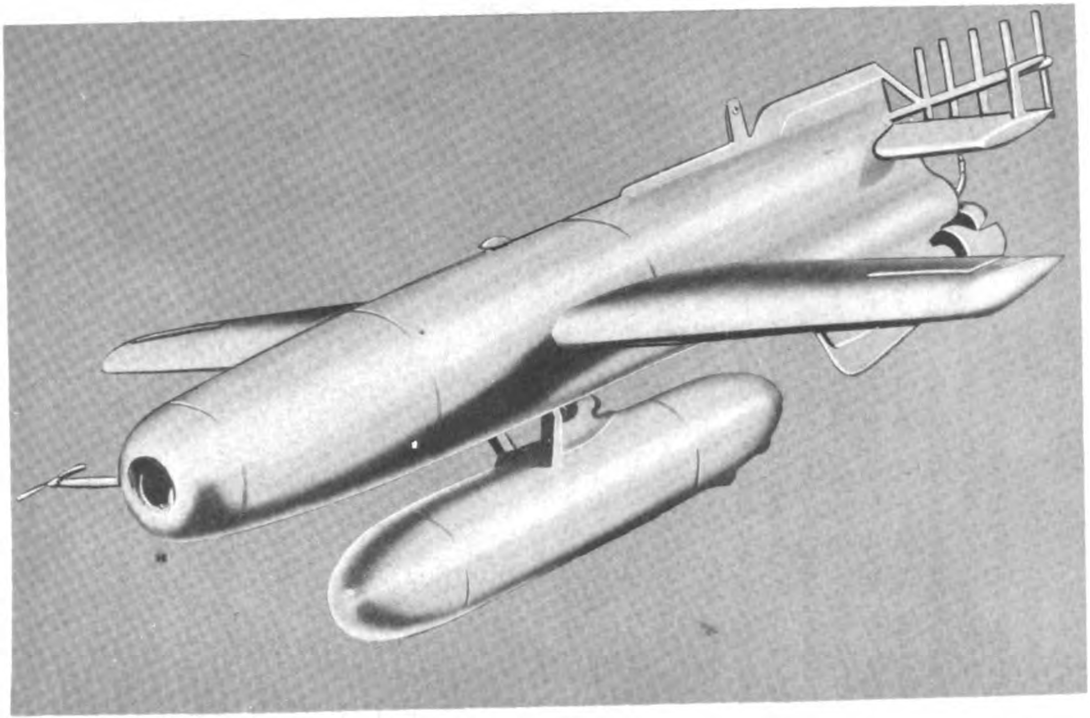


Figure 2–1.—German HS–293 radio-controlled glide bomb.

German scientists were more successful in the development of surface-to-surface and air-to-surface missiles. The launching of a radio-controlled glide bomb, the HS–293 shown in figure 2–1, began the long-awaited and much-dreaded era of guided missile warfare. In August 1943 a British convoy was steaming through the Bay of Biscay on the alert for enemy submarines and airplanes. The lookouts on one of the ships saw what appeared to be a small bomber come out of a turn and head directly toward the ship at an incredible speed. Antiaircraft guns attempted to shoot it down, but because of its small size and great speed, they did not stop it. As it approached the ship it did not drop a bomb and pull out of the dive in the familiar dive-bomber technique, but continued on its course until it struck the ship.

Here, for the first time in the history of warfare, a radio-controlled guided missile (which had been produced in sufficient quantities to affect the course of the war) was used. Although devices that might be classified as guided missiles had been used previously, they were primarily makeshift weapons such as remotely controlled airplanes.

Another air-to-surface missile of the same type was the FX–1400 bomb, shown in figure 2–2. It was a standard bomb fitted with a specially designed tail to receive the radio signals and control the aim of the bomb. Just why the Germans did not exploit and use more radio-controlled missiles is not known. However, they probably feared that these weapons could be easily countermeasured. This fear led them to develop mechanical control systems that were preset before launching. Such control systems were used almost exclusively in their long-range missiles.

Allied intelligence revealed as early as 1943 that the Germans had developed long-range guided missiles at Peenemunde. The first of these weapons, the V–1, was launched against England from the Pas de Calais area of France in June 1944. The buzz bombs (V–1's), powered by a pulse-jet motor, were launched from the ground at a range of about 125 miles.

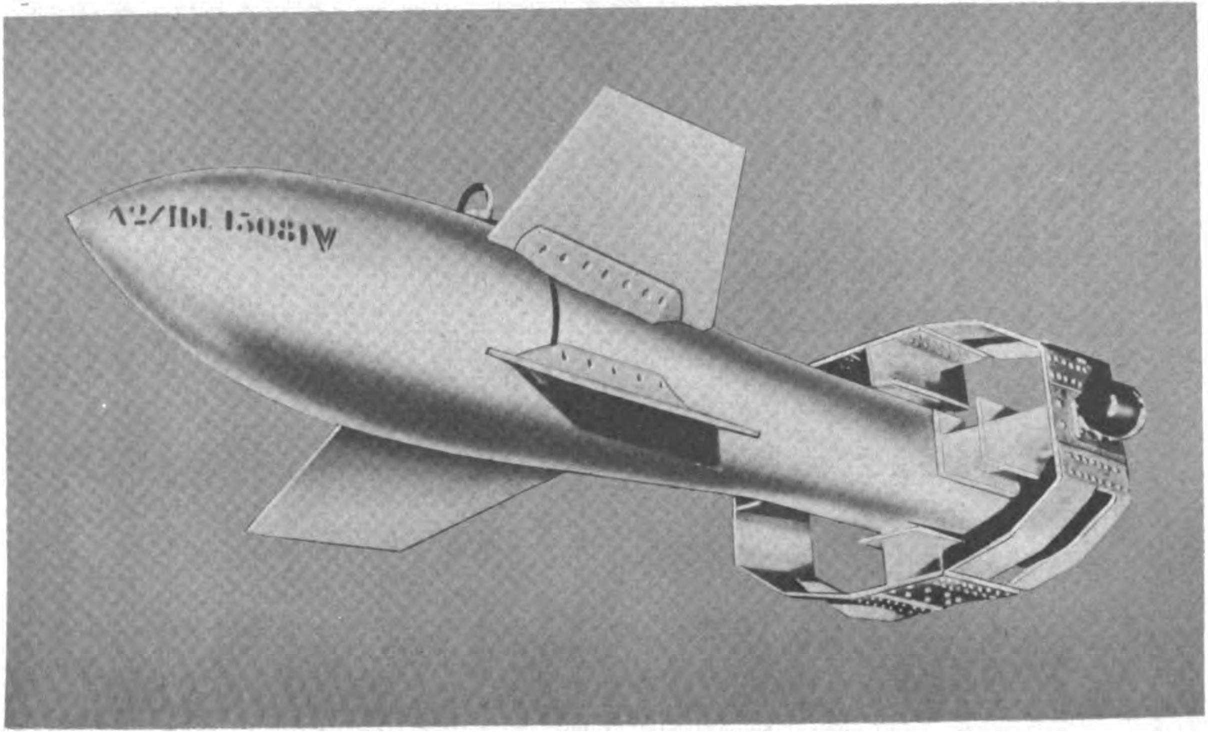


Figure 2-2.—German FX-1400 radio-controlled bomb.

During the next three months over 8,000 V–1 missiles were launched against England. The Allies overran the Pas de Calais launching area in September 1944, thus ending the first phase of the V–1 attacks. The Germans, however, were making new plans for continuing guided missile warfare, and England had to pass through two more phases of V–1 attacks. The second phase, which began with the air launching of the bombs, lasted from September 1944 to January 1945. During this period 1,012 launchings were recorded. But the Germans were losing air superiority and the second phase ended. The third and last phase of the V–1 attacks consisted of 158 ground launchings from Holland during March 1945.

As the first phase of the V–1 attacks was subsiding in September 1944, the Germans introduced the V–2 long-range missile shown in figure 2–3. The Allies were not surprised, for in the autumn of 1943 they received a report from Zurich that the Germans had fired 45-foot, 12-ton rockets over ranges up to 45 miles. Also in January, 1944, the Allies received reports from Stockholm that a missile, similar to the one mentioned above, rose to a height of 35 miles, traveled 65 miles before crashing, and cleared a circular area 600 yards in diameter in the forest where it crashed.

The V–2 was the first long-range rocket-propelled missile operated at supersonic speed to be used against an enemy. Although the V–2 was used operationally in large numbers, it was never fully developed. Continuous experiments were made with the component parts and many changes were made to improve its performance. Of the 2,676 missiles launched during the war, 1,314 were against Antwerp after it was captured by the Allies. About 65 percent of the missiles directed at Antwerp landed within a 6-mile radius of the center of the target.

The V–2 was propelled by a liquid-rocket motor burning liquid oxygen and alcohol and was designed to carry a payload of 1,654 pounds from 150 to 230 miles. It was launched vertically from the ground against fixed targets of large

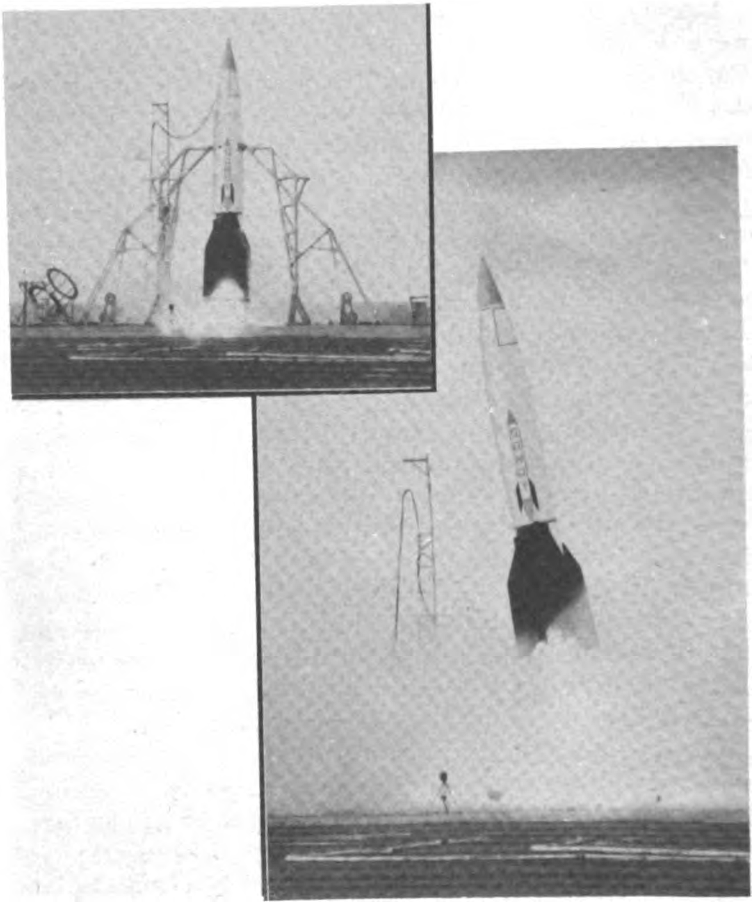


Figure 2–3.—The German V–2 missile.

area. After it had been in the air a few seconds, it tilted in the direction of the target. The amount of tilt during the climb period was preset according to the range of the target. At its maximum altitude of about 35 miles it reached a speed of approximately 3,300 miles per hour. The rocket motor was turned off and the missile continued on a

trajectory similar to that of an artillery shell. As it fell through the atmosphere it was slowed down to about 1,800 miles per hour at impact. The high altitude and supersonic speed of the V–2 made it practically impossible to countermeasure. Since it was supersonic, it would hit the target before it was heard approaching.

It is believed that if the Germans had been given a relatively short extension of time, they would have succeeded in developing antiaircraft missiles that would have seriously curtailed our bomber operations, and they would have produced superior surface-to-surface assault weapons which would have made the V–2 appear as a crude experiment. In general, the Germans were no further advanced than the Allies in design and engineering, but they were much further advanced in production and experimentation. The V–2 was by far the most outstanding achievement of all types of jet-propulsion devices produced before the end of World War II.

U. S. Development

In 1941 our Armed Forces became vitally interested in the development of guided missiles. Research based on newly discovered scientific principles of radar homing, aerodynamics, control of glide bombs, and pilotless aircraft had been under investigation for some time. Early success with target drones indicated the practicability of equipping them with warheads and crashing them into desired targets. This idea led to the development of special ASSAULT DRONES by the Navy Bureau of Aeronautics. The possibility of applying radar systems to glide bombs was suggested in a Navy Bureau of Ordnance Conference, and led to the development of the *Bat* missile.

Flying *Bat* bombs, launched from Navy planes, were the first FULLY AUTOMATIC guided missiles to be used successfully in combat by any nation. A closely guarded secret of the war, this guided missile was given the code name *Bat*, which suggests the principle on which it operates. Live bats give out a short pulse of sound and guide themselves by the

echo. Similarly, the *Bat* missile was directed by radar echoes from the target.

The *Bat*, shown in figure 2–4, is a bomb mounted in a glider type of airframe, which is equipped with (1) a radar transmitter and receiver which enables it to home on the target, (2) a stabilizing unit using a gyroscope for its reference, and (3) a system to move the control surfaces. It derives the power for its glide from its speed at release from the airplane and the pull of gravity.

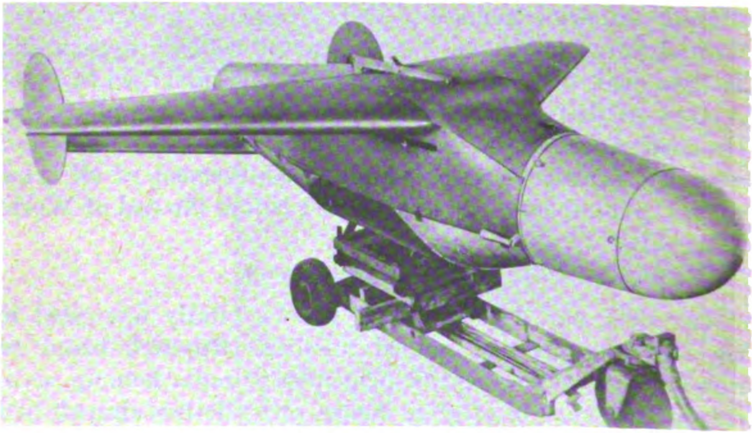


Figure 2–4.—The *Bat*.

The *Bat* was designed for use against ships, regardless of visibility, but also could be used against certain land targets. *Bat* bombs were used very effectively in World War II in destroying many tons of Japanese combat and merchant shipping.

Another important development in guided missiles during World War II was the *Azon*, shown in figure 2–5, so-called because the missile was controlled in azimuth only by remote radio signals. The *Azon* was a standard 1,000-pound bomb fitted with an extended tail that carried a flare, a radio receiver, a gyrostabilizer to prevent rolling, and rudders for steering to right or left.

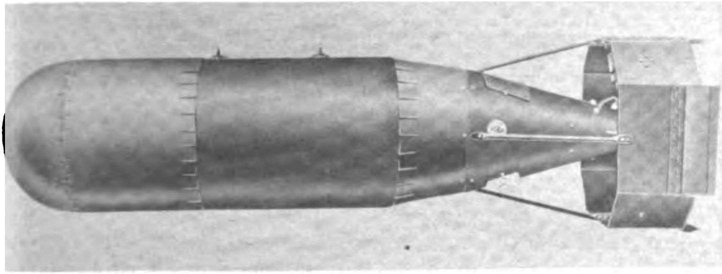


Figure 2–5.—*Azon* tail assembly mounted on a 1,000-pound bomb.

During World War II *Azons* were used by the Air Force in Italy, France, and Burma. In Italy several bridges were destroyed and the Avistio Viaduct leading to the Brenner Pass was put out of commission for a long time. In France several bridges, as well as important canal locks, were destroyed. The most effective use of *Azons* was in Burma where, for all practical purposes, enemy transport ceased to exist in December 1944. The *Azon* crews first destroyed the bridges and then blew up the substitutes as fast as they were built.

Basic research in the fields of radar and radio-controlled pilotless aircraft led to the development of the *Bat* and *Azon.* Another important field of physics which has excellent application to guided missiles is that of infrared, or heat radiation. All objects emit some heat radiation. Military targets such as ships, factories, and aircraft are in general warmer than their surroundings. The presence of these targets may be detected by the heat radiation they emit. Heat radiation is similar to ordinary light except that its frequency is lower, and it cannot be seen; but it can be detected by devices such as the thermopile (that is, a number of joined thermocouples), and bolometer. These devices are discussed in detail in a later chapter.

The *Felix* bomb, shown in figure 2–6, was the first guided missile which used the infrared radiation of the target. It was automatically guided by means of an infrared homing

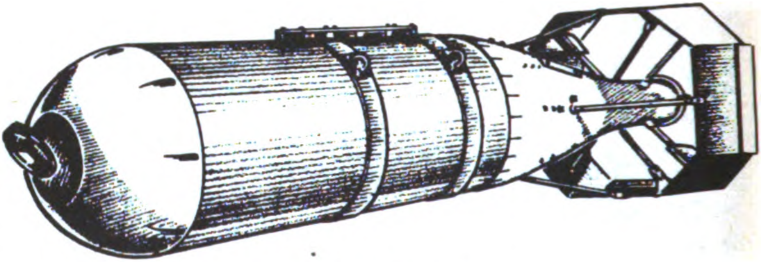


Figure 2–6.—*Felix* bomb.

device located in the nose of the bomb. The *Felix* was thoroughly tested and declared reliable and adequate for operational use, but the war ended before it could be used under combat conditions. The *Felix* missile represents a very important milestone in the development of present guided missiles. It opened the way to a new and different method of guidance, INFRARED HOMING.

The *Roc* missile, shown in figure 2–7, was designed to carry a radar homing device similar to the one used in the *Bat*. During the testing phase of the development program it became evident that the radar signals by which the missile was guided were not reliable at the steep glide angle

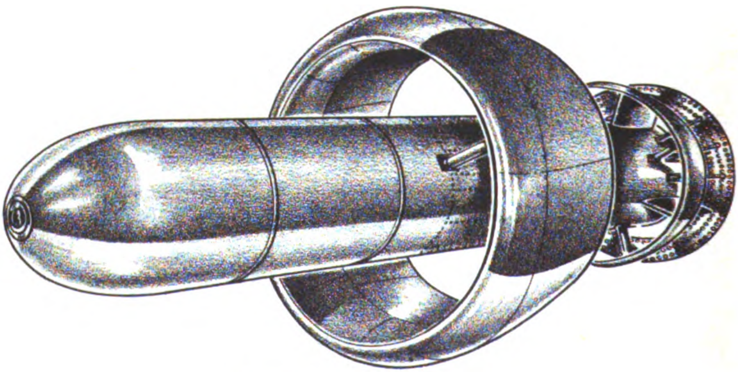


Figure 2–7.—*Roc* missile.

at which the *Roc* was designed to fly. A search was made for another method of guidance, and the final version of the *Roc* missile combined television equipment for transmitting a picture of the target to the launching airplane and a radio-control system for guiding the missile. This was the first use of television as a method of guidance.

The *Bat*, *Azon*, *Felix*, and *Roc* missiles were bombs improved by the addition of guidance equipment. Work on jet-propelled air-to-surface guided missiles was started early in 1943 by the Navy Bureau of Aeronautics with the *Gorgon* series of missiles. Later in 1943 a rocket-boosted air-to-surface missile, the *Gargoyle*, was developed. Figure 2–8 shows one of the missiles developed in the *Gorgon* series.

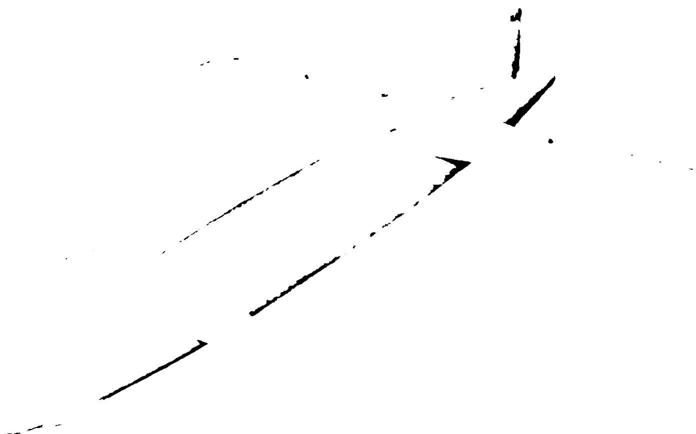


Figure 2–8.—*Gorgon* missile.

In 1944 fleet losses from Japanese Kamikazes and Bakas spurred the development of ship-to-air missiles. The first missile development in this program was the subsonic *Lark*, guided by a radar beam. The *Lark*, shown in figure 2–9, is presently used for training and test work in the development of guidance, launching, and handling techniques.

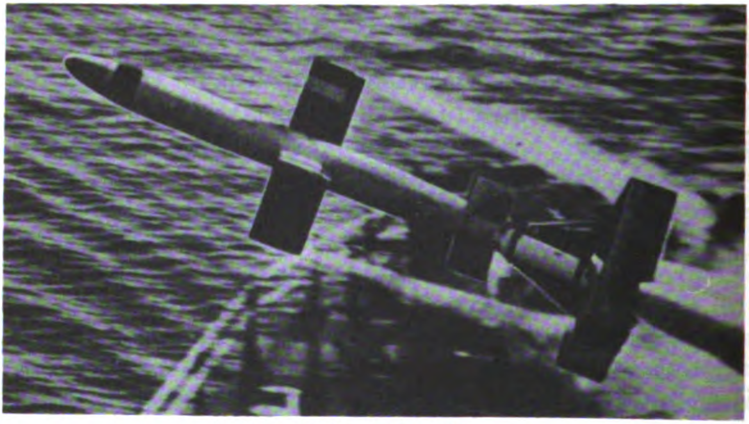


Figure 2–9.—*Lark* missile.

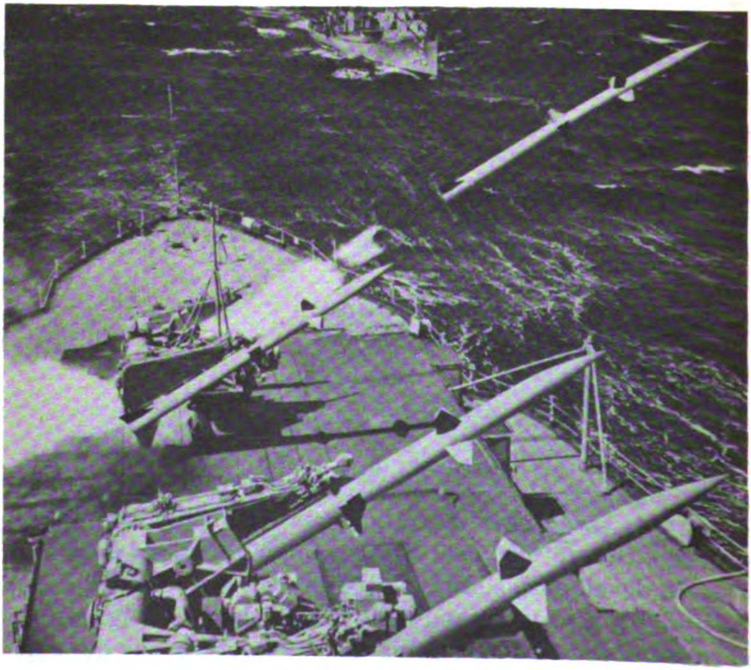


Figure 2–10.—*Terrier* missile.

The knowledge and experience gained in the development program of the *Lark* was used to develop a new and better missile, the *Terrier*. This missile, shown in figure 2–10, is a member of the Bumblebee family of guided missiles. It was originally designed as a test vehicle, to test the performance of various components of another missile, the *Talos*, in supersonic flight. It was later modified to produce a tactical missile. The *Terrier* is a surface-to-air guided missile employing a separate solid propellant booster rocket and an integral solid rocket sustainer motor which enables it to attain supersonic speeds. The primary tactical objective is the destruction of attacking aircraft at ranges and altitudes well beyond the bomb release point of these aircraft. Although it is primarily designed as an antiaircraft defense for ships, *Terrier* may also be used for the defense of shore stations. This surface-to-air missile, the first adopted by the Navy for operational use by surface ships, is presently installed in the guided missile cruisers and will be installed in aircraft carriers.

The *Regulus* missile is a turbo-jet powered, surface-to-surface, remote-controlled weapon. This missile was started in 1947 as a result of the basic requirements set forth by the Bureau of Aeronautics. Since 1947 extensive tests and modifications have been in progress from all standpoints of missile design. At this writing the *Regulus* may be launched from aircraft carriers, heavy cruisers and submarines; it is the surface-to-surface missile which the Navy has tested most extensively.

The modern jet fighter, with its high speed and large turning radius, has increased the range requirements of aircraft armament. Also, today's bombers are built much more rigidly, and greater explosive force and higher accuracy are required to destroy them. These factors have greatly reduced the effectiveness of aircraft armament such as the .50 caliber machinegun and the 20-mm cannon. In an effort to increase aircraft armament, the air-to-air rocket was de-

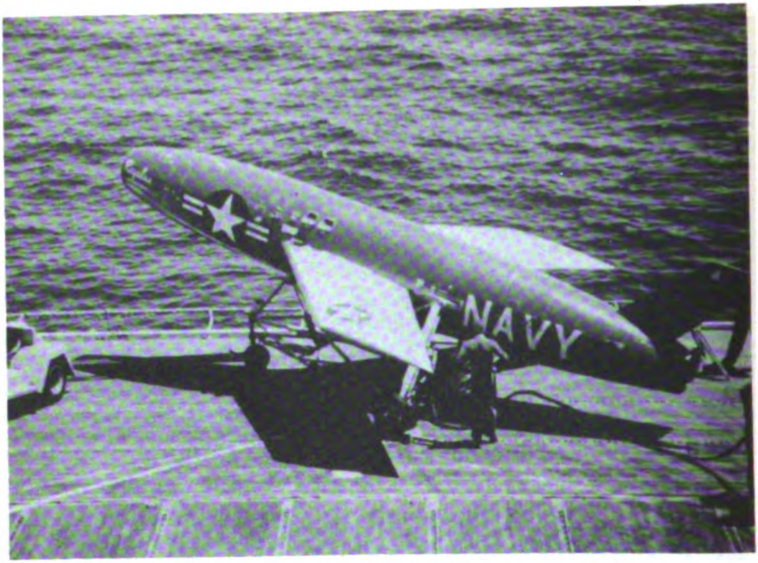


Figure 2–11.—The *Regulus*.

veloped. With the great strides made in research and development of guided missiles it became feasible to guide the air-to-air rocket by such methods as radar beam-riding or radio control. Also, a rocket can be equipped with a homing device which operates on the principle of radar, infrared, or sound.

The *Sparrow* is the first Navy air-to-air guided missile to become an operational weapon. A jet fighter armed with four *Sparrow* missiles is shown in figure 2–12. The *Sparrow* missile, shown in figure 2–13 is guided by a radar beam for a range of about five miles. A solid-propellant rocket motor boosts its speed to about 2.5 times the speed of sound, and one missile has enough destructive power to destroy a bomber.

Many other guided missiles have been designed during the research and experimental phases of developments. Many more will be developed. Those discussed here represent significant steps in the progress of present and future weapons.

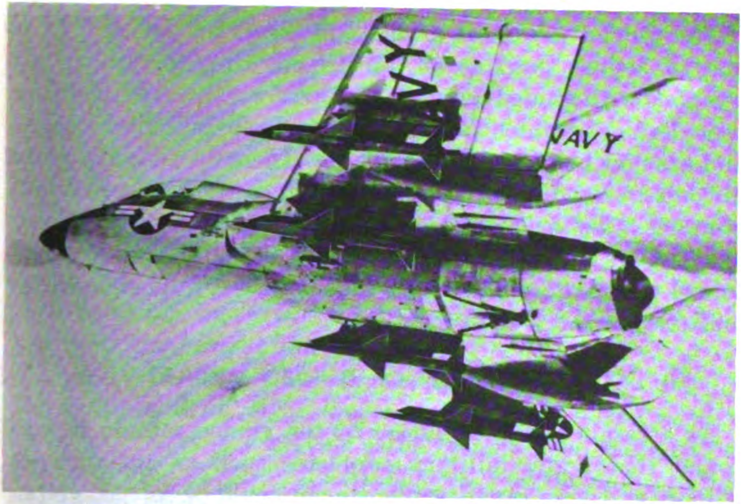


Figure 2–12.—Jet fighter with *Sparrow* missile mounted.

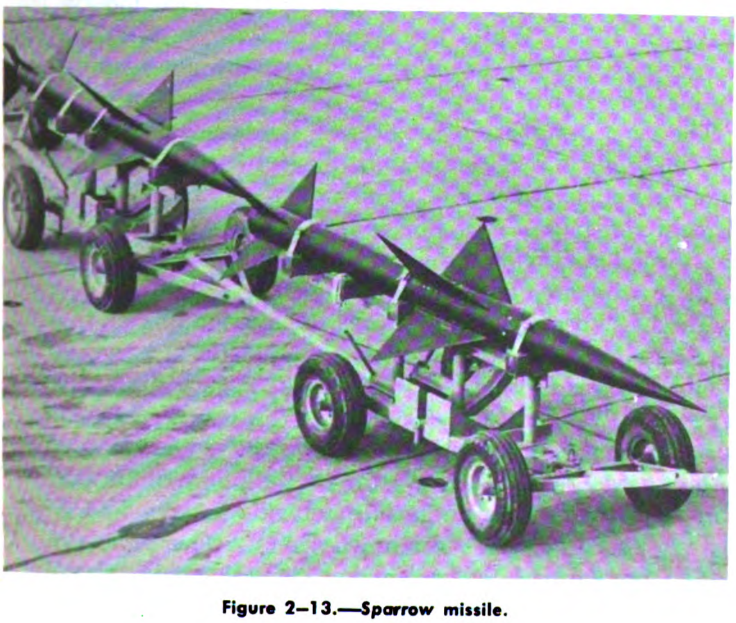


Figure 2–13.—*Sparrow* missile.

The guided missile is a new and powerful device. It is not, of course, possible at the present time to replace all weapons with guided missiles; however, certain missiles have been developed which are greatly superior to present weapons and are now being used in the fleet. These missiles are more difficult to handle, service, and maintain than conventional weapons. To make the most effective use of them the Navy has created the new rating, described in chapter 1, for personnel trained to maintain surface-launched guided missiles and associated test equipment.

CLASSIFICATION OF GUIDED MISSILES

As a result of the evolution of the guided missile it was found that many military problems such as antiaircraft defense and long-range bombardment could be solved. Specific application of the missiles led to the need of a simple classification system. This was designed for joint use by the Army, Navy and Air Force and adopted for use by the Navy in 1948. While the Army and Navy still employ this system, the Air Force now employs the system used for the classification of aircraft.

The type designation consists of symbols indicating status, mission, missile indication, developing agency, design number and modification. These symbols are divided into three major parts. The first indicates the basic designation, the second a service letter and the third a model number with an associated letter designation.

The basic designation indicates the mission of the missile. For missiles designed as military weapons it is a two-letter combination followed by the letter M, which indicates MISSILE. The first letter indicates the origin (launching place), and the second indicates the objective (target). The letters used are A for air, S for surface, and U for underwater. For example, an antiaircraft missile launched from the ground would be designated SAM. The basic designation for an air-launched guided torpedo would be AUM. Other basic designations are:

AAM, air-to-air missile
ASM, air-to-surface missile
SSM, surface-to-surface missile
SUM, surface-to-underwater missile
UAM, underwater-to-air missile
USM, underwater-to-surface missile

The second major part of the type designation is a service letter which indicates the agency responsible for the development of the missile. The service letters used are A for Army, and N for Navy. They are separated from the other parts of the designation by dashes.

One of the Armed Forces may design several missiles for the same mission. To indicate each design a model number is placed after the service letter in the type designation. For example, SSM–A–3 and SSM–A–5 would indicate two surface-to-surface missiles developed by the Army. Model 3 might be a short-range antitank missile and model 5 a long-range bombardment missile. When a particular missile is modified, a lower-case letter, beginning with "a" for the first modification, is added to the model number. For example, SAM–N–3b is the second modification of the SAM–N–3 missile. The model number together with the modification letter is the third major part of the type designation.

During the testing period by the service for whom the missile was designed the designation is preceded by the letter "X." This indicates that it is an experimental missile. For example, XSAM–N–9 is an experimental surface-to-air missile developed by the Navy and is the ninth design. After the testing period is completed and when the missile has become a production item, the letter "X" is removed and no other symbol is used in its place. When a missile is used for training, the basic designation is prefixed by the letter "T." This missile is intended for and limited to operational training for the parent missile. When the basic designation is preceded by an "R," it shows that the particular missile is a research or test missile constructed as a part of the parent missile program. For example, RSAM–N–6 is a research surface-to-air missile.

Research vehicles, which are not to be confused with research missiles, are designated by the letters "RV." This is the basic designation. The letters identifying the developing agency are the same as for missiles. That is "N" for the Navy and "A" for Army. Models and modifications have the same symbols as for missiles. For example, RV–N–1b is a research vehicle, developed for the Navy; it is the first model with the second modification.

TARGET DRONES

Target drones, with the exception of piloted aircraft converted to drones, are designated by symbols to indicate status, drone indication, developing agency, design number, and modification. The letter "X" is used for a target drone in the experimental, prototype of service-test stage. After the drone has undergone successful service tests and has become a production item, the "X" is dropped and no other symbol used in its place. The letters "KD" are used to indicate a target drone. A numeral is used to indicate the number, in consecutive order, of the designer's target drones, except that for the first design the numeral "1" is omitted. A letter is used to indicate the designer or prime contractor. A numeral following a dash after the designer letter is used to indicate the modification. The numeral "1" indicates the first model of the series, "2" the first modification, and so forth. For example, XKD5M–6 is an experimental target drone, fifth of Martin design, sixth modification. Note the difference between this system and that used for missiles.

With this brief history of missile development and the description of how missiles are designated, let us now see what factors affect a missile flight and what effects they have.

QUIZ

1. What are the five major items or systems which usually make up a guided missile?
2. Guided missiles generally possess which of the following improvements over conventional weapons?
   a. Increased range from the point of release to the target
   b. Increased destructive effect from improved accuracy or from larger destructive load
   c. Decreased susceptibility to countermeasures
   d. All of the above
3. The German World War II V–1 buzz bomb was powered by a
   a. liquid rocket motor with a range of about 500 miles
   b. pulse-jet motor with a range of about 125 miles
   c. solid rocket motor with a range of about 500 miles
   d. turbo-jet motor with a range of about 125 miles
4. The German V–2 had a range of 150 to 230 miles, a payload of 1,654 pounds, and was powered by a
   a. liquid rocket motor burning liquid oxygen and alcohol
   b. solid rocket motor
   c. liquid rocket motor burning hydrogen peroxide
   d. turbo-jet motor burning oxygen and alcohol
5. The U. S. World War II *Bat* weapon was
   a. an air-to-air guided missile guided by infrared homing
   b. an air-to-surface guided missile guided by radar target echoes
   c. a surface-to-air guided missile guided by a radar beam
   d. an underwater acoustic homing torpedo
6. The *Lark* is
   a. the first U. S. surface-to-air guided missile
   b. guided by radar echoes from the target
   c. a supersonic surface-to-air radar beam riding guided missile
   d. an air-to-surface radio command guided missile
7. The *Terrier* is
   a. a subsonic surface-to-air guided missile
   b. a glide bomb with an infrared homing device
   c. a surface-to-air antiaircraft guided missile
   d. a supersonic liquid rocket surface-to-air guided missile
8. The *Regulus* is a turbo-jet powered
   a. surface-to-air, remote controlled weapon
   b. surface-to-surface guided missile which is presently installed on USS *Boston* and USS *Canberra*
   c. surface-to-surface guided missile which may be launched from certain surface ships or submarines
   d. surface-to-air guided missile with infrared homing

9. Write the basic three letter designations which indicate the missions of each of the following classifications of guided missiles:
   a. air-to-air missile
   b. surface-to-surface missile
   c. surface-to-air missile
10. What are the three major parts of the type designations of Army and Navy missiles?
11. If a missile is in its experimental stage, its type designation is preceded by what letter?
12. What is the complete type designation for an experimental surface-to-surface missile developed by the Navy and in its second design?
13. Target drones, with the exception of ordinary aircraft converted to drones, are designated by symbols to indicate
   a. status, drone indication, developing agency, design number, and modification
   b. drone indication, status, developing agency, design number, and modification
   c. status, drone indication, design number, modification, and developing agency
   d. developing agency, design number, modification, drone indication, and status
14. What is the complete type designation of a surface-to-air missile used for research developed by the Army in its fifth design and third modification?

CHAPTER 3

FACTORS AFFECTING MISSILE FLIGHT

The study of the basic problems of missile flight, control, and stabilization properly begins with a description of the atmosphere, the medium in which the weapon travels. The atmosphere, the immense sphere of nitrogen, oxygen, and other gases in which we live, has well-defined physical properties, many of which are of primary importance in studies of the motions of guided missiles, as well as other types of aircraft. It is the purpose of this chapter to introduce some of these basic properties of the atmosphere, some of the elementary principles of aerodynamics, and to point out the more frequently used types of control surfaces and the methods in which they are employed in military missiles.

THE ATMOSPHERE

Most of the present-day guided missiles and those planned for future use will have at least a part of their flight path within the earth's atmosphere—a gaseous shell surrounding the earth with a height of roughly 250 miles. As a result, their efficient operation will be largely dependent upon the various effects associated with motion through the air. Also, in order to get very long ranges with self-propelled missiles, they must go very high and into regions of the atmosphere that possess different characteristics than those at sea level.

One of the most important characteristics of the atmos-

phere is the change with altitude in the DENSITY of the air. Density is the mass of air in a given volume. Because air is made up of gas particles, air density is also a measure of the number of particles in a given volume. For example, the number of gas particles in a cubic inch of air at sea level is about 420 billion billion; but at 35,000 feet the number of particles in a cubic inch is about only 110 billion billion.

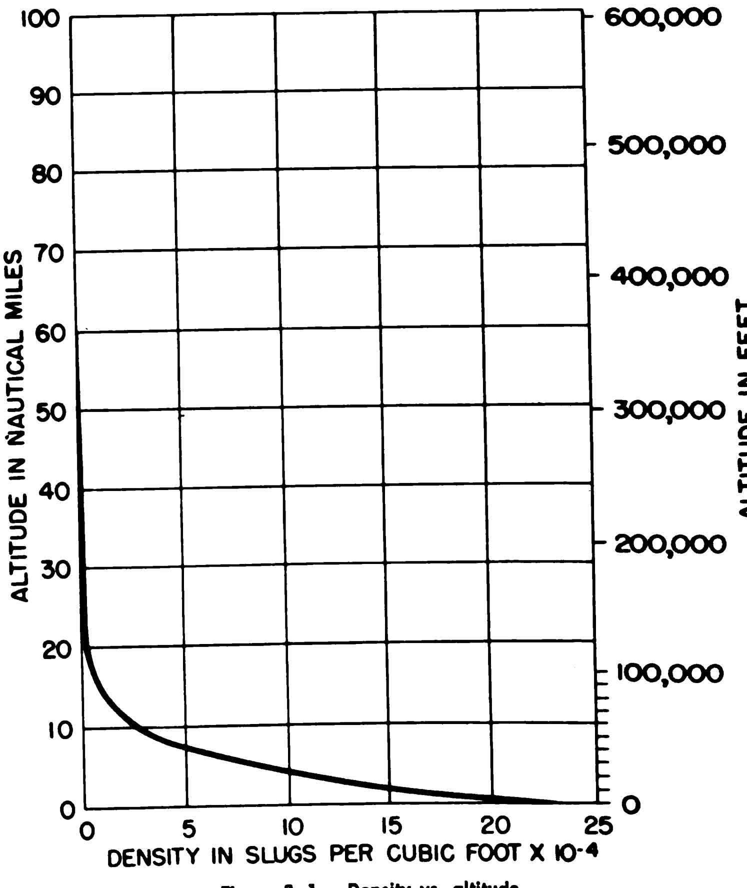


Figure 3–1.—Density vs. altitude.

Although this is still a very large number, it is only about one-fourth of 420 billion billion. As shown in figure 3–1, density changes very rapidly in the lower region of the atmosphere. (The unit "Slug" used here is equal to approximately 32 lbs.) This is because most of the air is concentrated near the surface of the earth—half of all the air particles that make up the atmosphere are packed in a layer

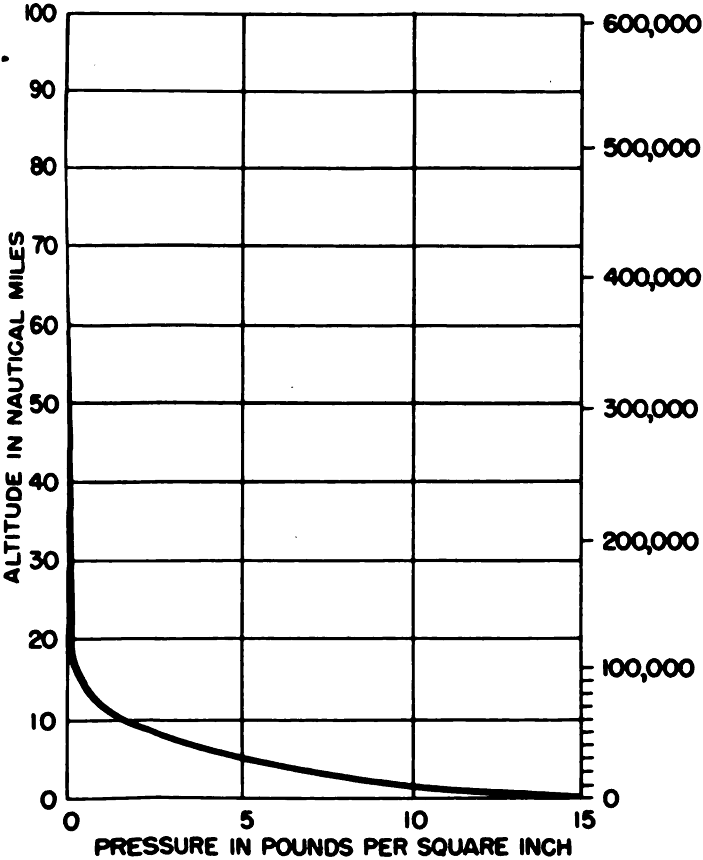


Figure 3–2.—Pressure vs. altitude.

between sea level and 18,000 feet. Because of this a missile flying at 35,000 feet encounters less air resistance—that is, has less drag—than a missile flying near sea level, simply because it hits fewer air particles per second.

Another characteristic of the atmosphere, which is closely associated with density, is the change with altitude in ABSOLUTE PRESSURE, shown in figure 3–2. The absolute pressure existing at any point in the atmosphere is the force per unit area exerted by the air against a fixed object. (If the object were moving with respect to the air, there would be a dynamic pressure acting on it, which would be in addition to the absolute pressure of the atmosphere.) Pressure is measured in force per unit area (for example, pounds per square inch). The absolute air pressure acting on each square inch in the earth's atmosphere at any given altitude is actually the weight of a square inch column of air extending from the altitude in question to the outer limit of the atmosphere. As a point of comparison, the increase in pressure only 34 feet below the surface of a lake is equivalent to the pressure developed on the earth's surface by the entire weight of the atmosphere.

Another characteristic of the atmosphere which also varies with altitude is the TEMPERATURE. However, it does not follow the same pattern as the density and pressure, except at low altitudes, as shown in figure 3–3. From sea level to about 35,000 feet the temperature usually drops steadily at the rate of approximately 3½° F. per 1,000 feet. It then remains fairly constant at −67° F. up to about 105,000 feet where it starts to increase at a steady rate until another constant-temperature zone is reached. This zone lasts for almost ten miles, at which point the temperature starts decreasing again. The procedure then repeats itself—that is, a second temperature minimum is reached, and then after a short, cold (about −27° F.), constant-temperature zone, it starts rising again. These temperature minimums mark the boundaries between the three regions of the atmosphere:

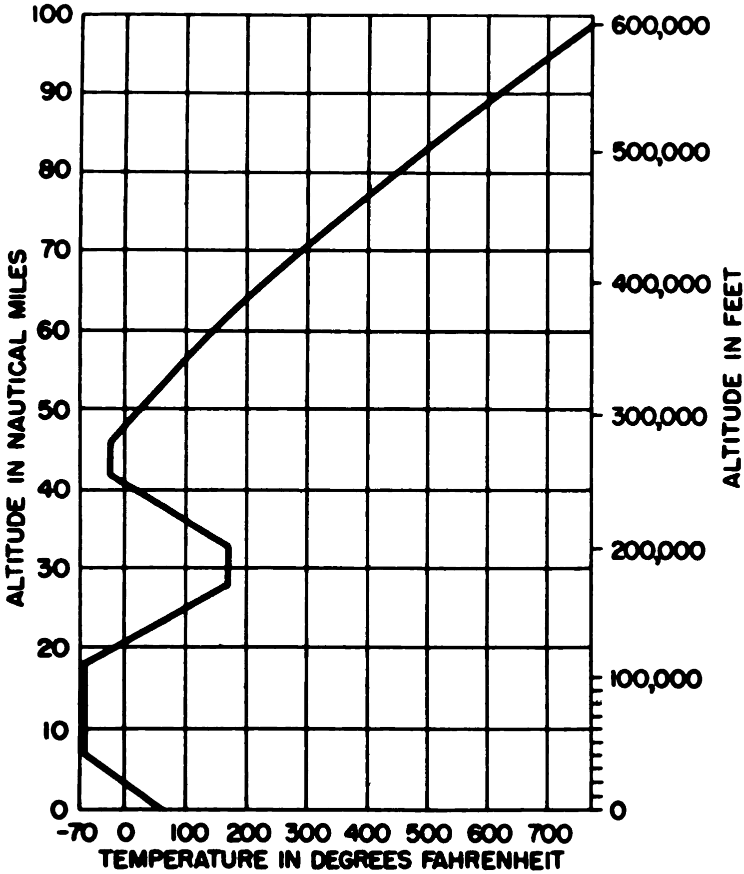


Figure 3–3.—Temperature vs. altitude.

the troposphere, the stratosphere, and the ionosphere, shown in figure 3–4.

The TROPOSPHERE is the lowest layer of the atmosphere, and extends from the surface of the earth to a height of about ten miles. It is made up of 99 per cent nitrogen and oxygen by volume, and accounts for three-fourths of the weight of the atmosphere. Within this layer temperature normally decreases with altitude; and you will find different

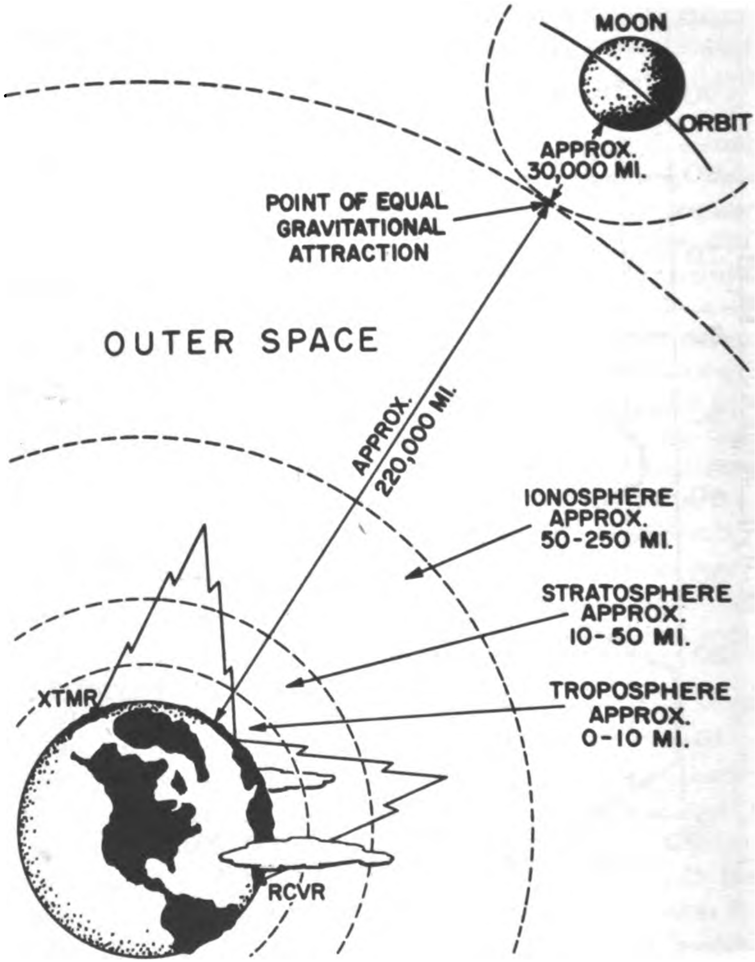


Figure 3–4.—Atmospheric regions.

types of clouds, either high above or resting on the ground (fog); snow, rain, hail, thunderstorms; and the four seasonal changes. In certain areas of the upper part of the troposphere prevailing westerly winds from about 100 to 300 miles per hour form the commonly called "jet streams."

Because of the high density of the troposphere, airfoils can be used efficiently for control of missiles in this region; and propellers are practical for low-speed power plants. However, this high density also causes a large amount of drag (the dense lower atmosphere slowed down the V–2 from 3,300 to 1,800 miles per hour) and if a missile travels at extremely high speeds, the friction of this dense air produces such high skin temperatures that ordinary metals will melt.

The STRATOSPHERE is the layer of air above the troposphere and ranges in altitude from about 6 to 10 miles to around 40 to 50 miles. In this region temperatures no longer decrease with altitude but stay somewhat constant, and even begin to increase in the upper levels. This higher temperature in the upper portion is caused by a concentration of ozone which is heated by ultraviolet radiation from the sun, and it may reach approximately 170° F. (Ozone is a gas which is produced when electricity is discharged through oxygen.) The composition of the stratosphere is similar to that of the troposphere; however, there is practically no moisture there. Propeller-driven vehicles cannot penetrate this region because of the low density of the air, and airfoils have greatly reduced effect in controlling a missile.

Above the stratosphere and ranging up to about 250 miles is the IONOSPHERE. This is a region rich in ozone and in ionized particles, and consists of a series of electrified layers that envelop the earth. This region is extremely important because of its ability to refract, or bend, radio waves. This property enables a radio transmitter to send waves to the opposite side of the world by a series of refractions and reflections taking place in the ionosphere and at the surface of the earth. The layers of the ionosphere change from daylight to darkness; they vary with the seasons of the year; and they are not identical above all areas of the earth. Little is known about the physical characteristics of this region. Our Armed Forces are continually sending instru-

ment-carrying rockets into it to obtain information about the temperatures, the pressures, the composition of the air, and the electrical characteristics of the various layers.

BASIC FLIGHT PRINCIPLES

Guided missiles in flight in the atmosphere are subject to the laws of aerodynamics, the science that deals with the motions of air and other gases and with the forces acting on solid bodies in motion through these gases. The principles of low-speed aerodynamics, which underlie the operation of most aircraft, also apply to missiles, at least in some phases of flight. But these alone are not sufficient to account for all the effects encountered, since most missiles travel at speeds near sound velocity or greater. Before discussing high-speed flight, however, it is necessary to consider the motions and forces that are common to both guided missiles and conventional airplanes flying at comparatively low speeds.

As a beginning, consider first the motions the missile must perform as it responds to signals from the control system and maintains the proper flight attitude. Like any moving body, the guided missile executes two basic kinds of motions: rotation and translation. In pure rotation all parts of the body pivot about the center of gravity, describing concentric circles around it. In movements of translation, or linear motions, the center of gravity of the body moves along a line, and all the separate parts follow lines parallel to the path of the center of gravity. Any possible motion of the object is composed of one or the other of these fundamental motions or else is a combination of the two.

Missiles, like other forms of aircraft and like submarines, are free to move in three dimensions. Consequently, to describe their motions it is necessary to use a reference system containing three separate reference lines, or axes. The missile axes, illustrated in figure 3–5, are three mutually perpendicular lines which intersect at the center of gravity of the airframe. The terms applied to them are identical with those used for other forms of aircraft.

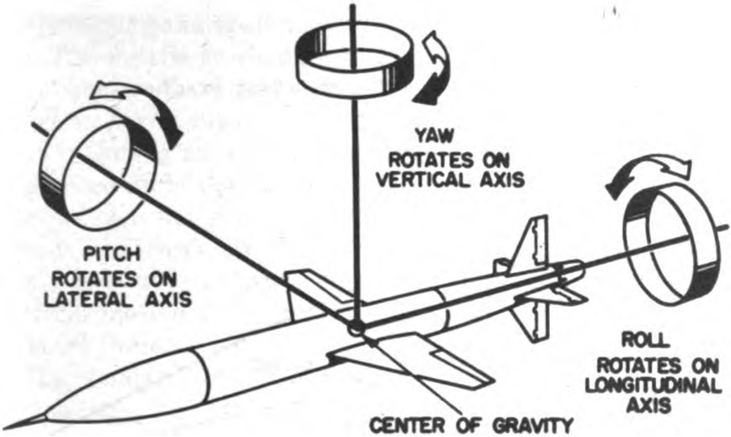


Figure 3–5.—Missile axes.

Three kinds of rotary movements can be made by the missile: pitch, roll, and yaw. PITCH, or turning up or down, is a rotation about the lateral axis, the reference line in the horizontal plane running perpendicular to the line of flight. The missile ROLLS, or twists, about the longitudinal axis, the reference line running through the nose and tail. It YAWS, or turns to the right or left, about the vertical axis. Rotary motions about any of the three axes are governed by the steering devices of the missile such as the aerodynamic control surfaces. A fourth motion necessary for control as well as for flight is the motion of translation, the forward movement resulting from the thrust provided by the propulsion system.

FLIGHT FORCES

The principal forces acting on a missile in level flight are thrust, drag, weight, and lift. Like any other force, each of these is a vector quantity which has by definition, magnitude (length), direction, and sense (positive or negative). These forces and their directions are illustrated in figure 3–6.

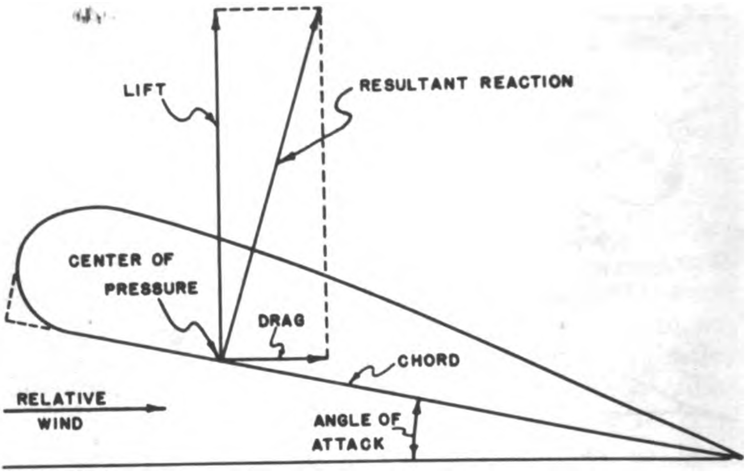


Figure 3–6.—Forces acting on a moving missile.

THRUST, which is supplied by the propulsion system, is directed along the longitudinal axis of the missile and is the force which propels it forward at speeds sufficient to sustain flight. Drag is the resistance offered by the air to the passage of the missile body through it and is directed rearward, acting along the line of airflow past the airfoil surfaces. The weight of the missile is the force of gravity of the body and directed downward toward the center of the earth. Opposed to the force of gravity is the lift, a highly desirable force in a missile produced by the moving airfoil which supports the body and which is directed perpendicular to the direction of drag.

ACCELERATION.—In level flight at a constant speed thrust is exactly balanced by drag and the lifting force exactly cancels the weight of the body. If any one of these basic forces is changed, the result is acceleration in a positive or negative sense. Acceleration in flight is change, either in speed or in the direction of motion. It occurs in two ways:

1. The missile accelerates in a positive or negative sense as it increases or decreases speed along the line of flight.

This type of acceleration takes place in missile flight during launching and upon impact with the target.

2. The missile accelerates in a positive or negative sense if it changes the directions in which it is moving, for example in turns, dives, pullouts, and as a result of gusts of wind. During an acceleration change of this sort while in high speed flight the missile is subjected to large forces which tend to keep it flying along the line of its previous flight. This is in accordance with Newton's first law of linear motion which states: a particle remains at rest or in a state of uniform motion in a straight line unless acted upon by an external force.

The standard unit of acceleration is gravity, abbreviated by the letter "g." A body falling freely in space is pulled downward with a force equal to its weight with the result that it accelerates at a constant rate of approximately 32 feet per second per second. Its acceleration while in free fall is said to be one "g." Missiles making rapid turns or while responding to large changes in thrust will experience an acceleration a number of times that of gravity, the ratio being expressed as a number of "g's." The effect of the force of acceleration on the body is the same as if its weight had been multiplied by a factor equal to the number of "g's" imposed on the body. The number of "g's" which a missile can withstand is one of the factors which determines the maximum turning rate and the type of launcher suitable for the weapon, since the delicate instruments of the control and guidance system may be damaged if subjected to accelerations in excess of a design value.

Production of Lift by Airfoils.—Lift, the force upon which flight depends in the atmosphere, is produced by means of pressure differences. The primary factor which is necessary for the lifting action of an airfoil is that the air pressure on the upper surface of the airfoil must be less than the pressure on the underside. The airfoil, then, is simply a device for creating pressure differences when in motion. The amount of lifting force provided is dependent to a large

extent on the shape of the airfoil or wing. Additional factors which determine lift are the wing area, the angle at which the wing surface is inclined to the airstream, and the density and relative speed of the air passing around it. The airfoil that gives the greatest lift with the least drag in subsonic flight has a shape similar to the one illustrated in the three parts of figure 3–7. The cross section shows a rounded nose, a smoothly arched or cambered top, and a sharp trailing edge.

Some of the standard terms generally applied to airfoils are included in the sketch. The foremost edge of the wing shown in (A) is called the LEADING EDGE, and that at the rear is called the TRAILING EDGE. A straight line drawn between the leading and the trailing edges is called the CHORD; and the maximum distance measured from one wingtip to the other is known as the SPAN. The relation between the average chord and the span is known as the ASPECT RATIO. In (C) of figure 3–7 the arrow symbolizes the RELATIVE WIND,

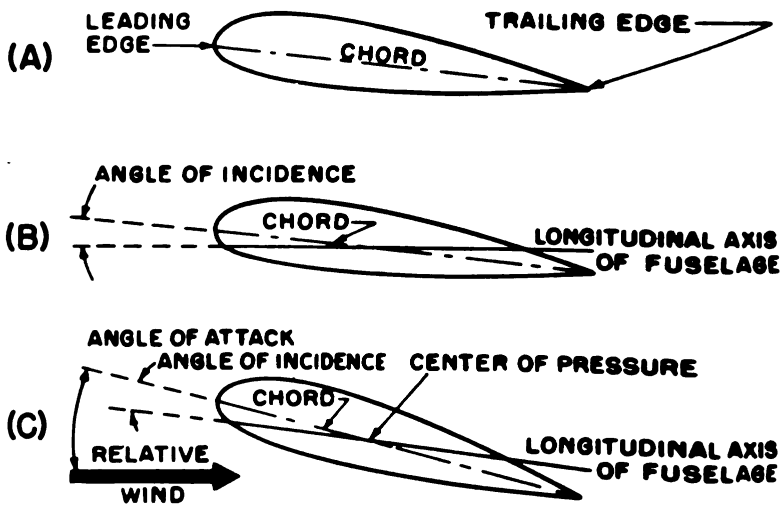


Figure 3–7.—Wing cross section.

the direction of the airflow with reference to the moving airfoil. In flight the ANGLE OF ATTACK is the angle between the wing chord and the direction of the relative wind. The angle between the wing chord and the longitudinal axis of the fuselage is called incidence angle, as shown in (B) of the figure.

The relative wind strikes the tilted surface, and as the air flows around the wing different amounts of lifting force are exerted on the various areas of the airfoil. The sum, or resultant, of all these component forces is equivalent to a single force acting at a single point and in a particular direction. This point is called the center of pressure; and from it the resultant force of lift is directed perpendicular to the direction of the relative wind.

Lift may be considered as resulting from two general causes: one from dynamic pressures, or the pressure of air in motion; and the other from differences in the static pressure of the atmosphere, which is exerted on bodies by the weight of the column of air above them. The dynamic pressure of the relative wind against the underside of the wing accounts for a fraction of the total lift—at most about one-third of it. The remainder is produced by a difference of the static pressures on the upper and lower surfaces. The principal lifting effect is the result of air flowing over the upper wing surfaces with increased velocity and an accompanying decrease in pressure. The principle involved in such pressure reduction was first announced many years ago by a Swiss physicist, Daniel Bernoulli.

In the form in which it applies to airfoils, Bernoulli's principle is as follows: air pressure decreases when air velocity increases. This relationship is illustrated in figure 3–8 in the action of the venturi tube, a hollow cylinder containing a constriction, or narrow section, through which a fluid is passing. The rate of flow increases when the fluid passes through the constriction since it must travel a greater distance in following the curved walls of the tube. In this case the Bernoulli principle says that in the narrow section the pres-

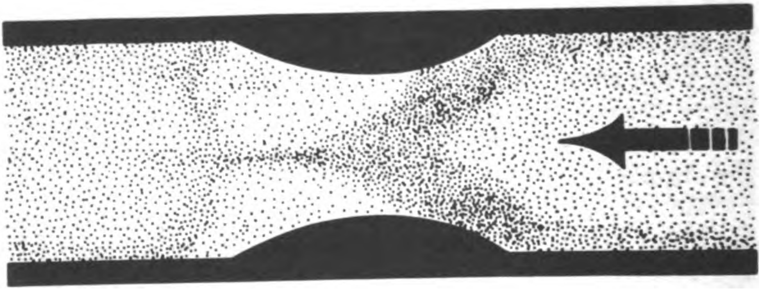
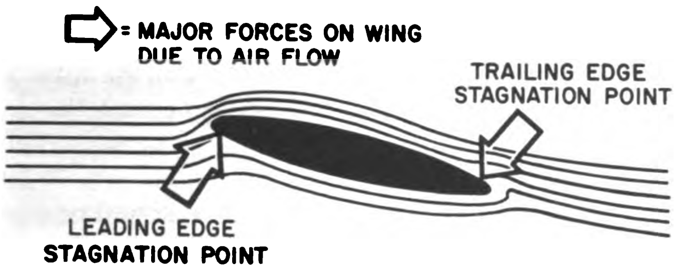


Figure 3–8.—Application of Bernoulli's principle.

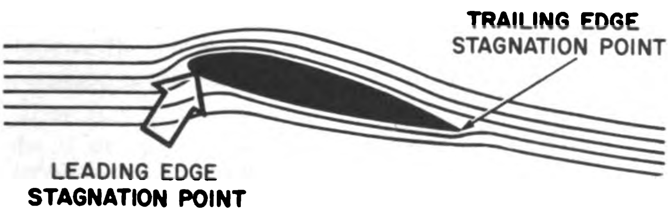
sure exerted laterally against the walls of the tube is less than the lateral pressures on the walls upstream and downstream from this section, and that the difference in pressure results from the increased velocity of flow.

The same relation exists in the streams of air flowing over the upper and lower surfaces of the wing. During flight, part of the approaching air is forced to flow over the longer path of the curved upper area, and its velocity is thereby increased compared with that of the air passing over the shorter path along the underside. The difference in the flow rate causes a difference in the lateral pressures on the two surfaces, and a net force is then present which is directed upward. This force is the greater part of the total lift supporting the weight of the aircraft, the remainder being supplied by the effect of dynamic or impact pressure.

The part that the trailing edge plays in producing lift is illustrated in figure 3–9. The air flowing over the top of the wing joins the airstream from the lower surface at the trailing edge. If this edge were rounded, as in (A) of the figure, the lower stream would curve around to the upper surface and a second high-pressure STAGNATION POINT, a point at which a



A. WING WITH ROUNDED TRAILING EDGE



B. WING WITH SHARP TRAILING EDGE

Figure 3–9.—Necessity for a sharp trailing edge.

moving fluid comes entirely to rest, would then form on the top of the wing. Its effect would oppose the lifting force. But if the trailing edge is made sharp, as in (B), the airstream does not make the turn to the topside surface and no undesirable force is produced on the after part of the airfoil.

Turbulence and Stall Conditions.—The whole matter of lift is concerned with the smooth flow of air over and under the wing. With this in mind, it is easy to understand what takes place when an aircraft (or missile) goes into a stall. Up to a point, as the angle of attack of an airfoil is increased, the lift also increases, since the high value of angle causes the air flowing over the upper part of the wing to travel a greater distance. Hence the airflow increases in speed and

the pressure difference which produces lift is thereby increased. But if the angle of attack is made too great, lift is destroyed by the formation of turbulence on the upper airfoil surfaces. This condition is shown in figure 3-10.

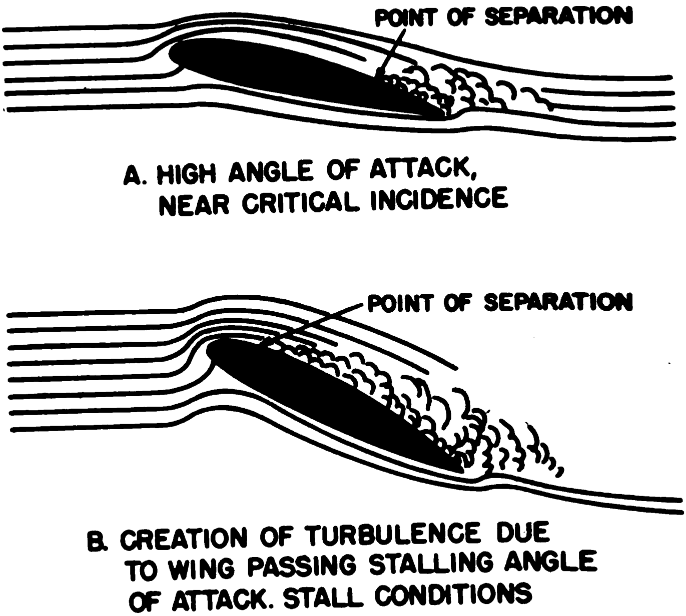


Figure 3-10.—Turbulence and stall conditions.

At moderately high angles of attack, the flowing air can follow the initial turn of the leading edge but it cannot follow the wing contour completely; then the stream separates from the surface near the trailing edge. Further increase of the angle causes the point at which the separation occurs to move forward. At some value of attack angle, the separation point is placed so near the leading edge that the upper airflow is disrupted, flight characteristics disappear, and the wing is in a stall.

Mach Numbers and Speed Regions

Missile speeds are generally expressed in terms of MACH NUMBERS rather than in miles per hour or in knots. The Mach number of any moving body is the ratio of its speed to the speed of sound in the surrounding medium (local speed). For example, if a missile is flying at a speed equal to one-half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2. (The term MACH NUMBER is derived from the name of an Austrian physicist, Ernst Mach, who was a pioneer in the field of aerodynamics.)

SPEED OF SOUND.—The speed expressed by the Mach number is not a fixed or constant quantity since the speed of sound in air varies with temperature. Sonic speed varies directly with the square root of the absolute temperature (the temperature in degrees centigrade plus 273) of the air, and therefore it is different in different localities. For example, it decreases from 760 miles per hour (MPH) at sea level (for an average day when the air is 59° F.) to 661 MPH at the top of the troposphere. The speed of sound remains constant (with the temperature) at from 35,000 feet to 105,000 feet of altitude, then rises to 838 MPH, reverses, and falls to 693 MPH at the top of the stratosphere.

The speed of sound is taken as a reference figure for highspeed flight, not because sound is involved directly, but because sound is a series of pressure variations. Its local speed, then, is the rate at which pressure disturbances from a flying body spread out through the air around it. If the missile or other aircraft moves much slower than the pressure waves it causes, the air through which it flies is said to be INCOMPRESSIBLE, that is, air flowing over its surfaces undergoes changes in pressure with little change in density. But as the speed of the missile approaches or exceeds the local speed of sound, the airflow is said to be COMPRESSIBLE, and forces are then present which cause this kind of flight to differ considerably from that at low-speed conditions. Thus, the amount of compressibility present depends on the Mach number of the moving body.

Regions of Speed.—The total range of aircraft and missile speed is divided into four basic regions which are defined with respect to the local speed of sound. These regions are as follows:

1. Subsonic flight, in which the airflow over any surface of the airfoils is less than the speed of sound. The subsonic division starts at Mach 0 and extends to about Mach 0.75. The upper limit varies with different aircraft, depending on the design of the airframe.

2. Transonic flight, in which the airflow over the surfaces is mixed, being less than sonic speed in some areas and greater than sonic speed in others. The limits of this region are not sharply drawn, but it is usually considered to extend from about Mach 0.75 to Mach 1.2.

3. Supersonic flight, in which all the airflow over the surfaces of the airfoils occurs at speeds greater than sound velocity. This region extends from the upper limit of the transonic region (about Mach 1.2) upward.

4. Hypersonic flight, in which the time of passage of the missile is of the order of "relaxation" time. Relaxation time is the time required for molecules of air to adjust themselves to the presence of a body or to readjust themselves after the passage of the body. Mach numbers on the order of 10 may be considered as hypersonic. Velocities that are not hypersonic at sea level may become so at high altitudes, since relaxation times will be longer where densities are relatively low.

Subsonic Flight

At subsonic speeds sustained flight by missiles and other heavier-than-air craft is dependent on forces produced by the motion of aerodynamic surfaces through the air. If the surfaces of airfoils are well designed, the stream of air flowing over, under, and around them are smooth, conforming to the shapes of the airfoils. If, in addition, the airfoils are set to the proper angle and if the motion is fast enough, the air flow will support the weight of the aircraft or missile.

Control of missiles and jet aircraft in the transonic and supersonic regions differs somewhat from that at subsonic speeds. Particularly in the transonic region are the effects varied, depending mainly on the individual characteristics of the missile or aircraft involved. If these have been specifically designed for these speeds, the effects are not serious or dangerous. But when aircraft or missiles not so designed venture into the transonic speeds, unpredictable and sometimes fatal results may occur. For example, the nose may "tuck down" and the control system may be unable to restore normal flight. In some the wings and control surfaces may begin to vibrate violently, or "buzz," upon entering the transonic region. In some cases the controls become reversed, and the action which usually results in a turn to port may result in one to starboard instead. These effects and many others result from COMPRESSIBILITY, a property of the airstream which is not prominent at low speeds but which cannot be ignored as the airspeed progressively increases.

It is important to remember that air, like any other gas, is compressible regardless of speed. Compressibility is not something which suddenly appears; it builds up with an increase of speed. It is principally in transonic flight that compressibility is capable of causing the effects mentioned above.

THE NATURE OF COMPRESSIBILITY.—When an object moves through the air, it continuously produces small pressure disturbances in the airstream as it collides with the air particles in its path. Each such disturbance—a small variation in the pressure of the air—is transmitted outward in the form of a weak pressure wave. Each expanding pressure wave travels at the speed of sound since sound waves in themselves are nothing but pressure variations. Although each pressure wave expands equally in all directions, the important direction is that in which the object generating it is moving.

As long as the object is moving at a low subsonic speed, its position in space with respect to the pressure wave it pro-

duces is similar to that shown in (A) of figure 3–11. The pressure wave expands in all directions; and since its speed is high compared with that of the body, the variation in pressure travels well ahead and agitates the air particles in the path of motion. Hence, when the body arrives at any given point, the air particles there are already in motion and can easily and smoothly conform to its shape and flow around it.

In (B) and (C) of the figure the object is represented as increasing in speed but as still traveling below the sonic velocity. As its speed increases, the object at any moment is situated proportionately nearer the undisturbed air particles in its path. This means that the greater the speed of the

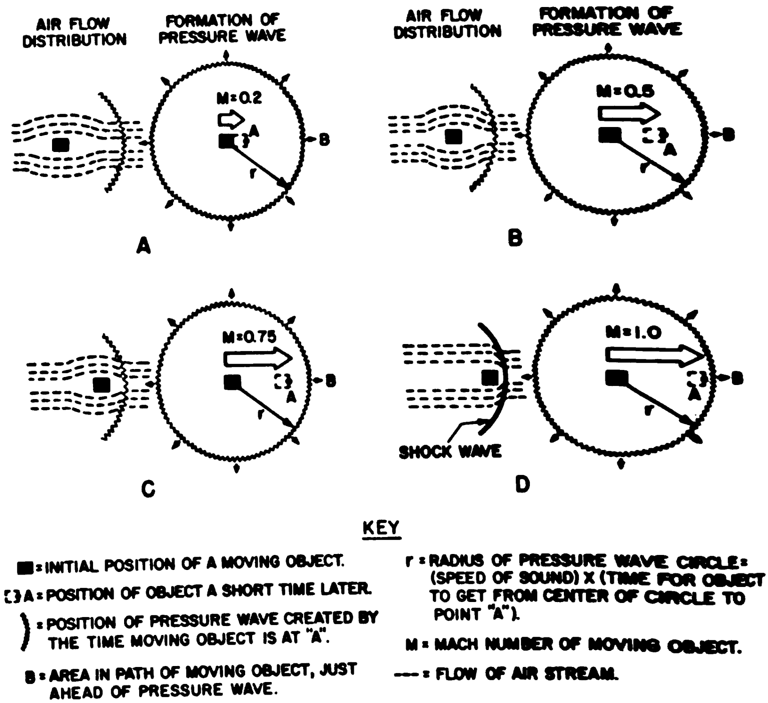


Figure 3–11.—Compressibility at various speeds.

moving body, the fewer the number of air particles that will be able to move from its path, with the result that the air begins to pile up in front of the body.

When the object reaches the speed of sound, the condition represented in (D) of figure 3–11 occurs. The pressure wave can no longer outrun the object and prepare the air particles in the path ahead. The particles then remain undisturbed until they collide with the air that has piled up in the airstream just ahead of the object. As a result of the collision, the airstream just ahead of the object is reduced in speed very rapidly; at the same time its density, pressure, and temperature increase.

As the speed of the object is increased beyond the speed of sound, the pressure, density, and temperature of the air just ahead of it are increased accordingly; and a region of highly compressed air extends some distance out in front of the body. Thus a situation occurs in which the air particles forward of the compressed region at one moment are completely undisturbed, and at the next moment are compelled to undergo drastic changes in velocity, density, temperature, and pressure. These abrupt changes occurring in the airstream are illustrated by the graph shown in figure 3–12. Because of the sudden nature of the transition, the boundary between the undisturbed air and the compressed region is called a SHOCK WAVE.

In summary, the following can be said concerning the nature of compressibility and its effects: the greater the speed of a blunt body moving through air, the greater is the air density and air pressure directly in front of it, and the less smooth is the flow of air around it. At comparatively low speeds the density changes of the air due to its compressibility can be ignored. But at airspeeds of about Mach 0.3, the density changes begin to be increasingly important. In general this effect is an aid to lift until the airstream at any point on the wing surface exceeds the speed of sound. When this happens, sudden changes in the conditions of the air take place due to the formation of shock waves.

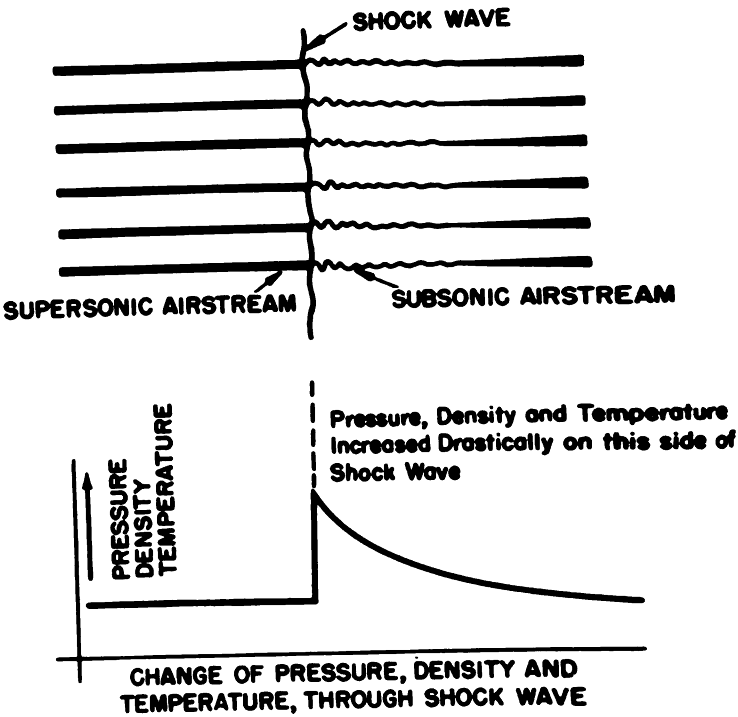


Figure 3–12.—Physical changes occurring in a shock wave.

SHOCK WAVES.—There are several types of shock waves, the principal classes being the NORMAL and the OBLIQUE. These two differ primarily in the way in which the airstream passes through them. In the normal (or perpendicular) wave, the air passes through without changing in direction, and the wavefront is perpendicular to the line of flow. The normal shock wave is usually very strong; that is, the changes in pressure, density, and temperature within it are great. The air passing through the normal shock wave always changes from supersonic to subsonic velocity.

Oblique shock waves are those in which the airstream changes in direction upon passing through the transition marked by the wavefront. These waves are produced in

supersonic airstreams at the point of entry of wedge-shaped and other sharply pointed bodies; and the resulting wave-fronts make angles of less than ninety degrees with the axis of motion. Like the normal shock wave, the oblique wave occurs at a point of change in velocity from a higher to a lower value. The change in speed is usually from supersonic to subsonic but not always so. In some cases the airflow is supersonic both upstream and downstream of the oblique wave. In general, the variations in density, pressure, and temperature are less severe in the oblique wave than in normal shock waves.

Normal shock waves can be formed in different ways. They occur when blunt objects are placed in supersonic airstreams. They can also form in an airflow which contains no interfering object, provided the air makes rapid changes in velocity, an example being the flow in a venturi tube. In a similar manner, normal shock waves can occur over the wing surfaces of a subsonic aircraft that exceeds its maximum safe operating speed. The formation of the shock wave in this latter case is illustrated in figure 3–13.

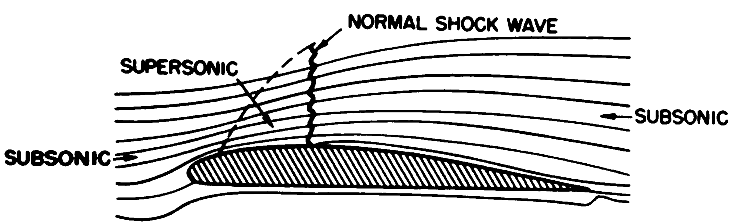


Figure 3–13.—Formation of normal shock wave on airfoil.

In the figure the high-speed (but still subsonic) airstream flows up over the leading edge of the wing, increasing in velocity as it does so, and passes the speed of sound. At a point on the wing slightly rearward of the leading edge, the velocity of the flow decreases, changing from supersonic to a subsonic value. At the point of transition a normal shock wave is formed. This process illustrates the following rule which always holds true:

The transition of air from subsonic to supersonic flow is always smooth and unaccompanied by shock waves; but the change from supersonic to subsonic flow is always sudden and is accompanied by large variations in pressure, density, and temperature. These variations take place at the point of formation of a shock wave.

Figure 3–14 shows the formation of a shock wave on the airfoil of an aircraft flying just fast enough to cause supersonic flow over the top of the wing. If the speed of the air is further increased, the conditions illustrated in figure 3–14 are present. The area of supersonic flow increases, and the

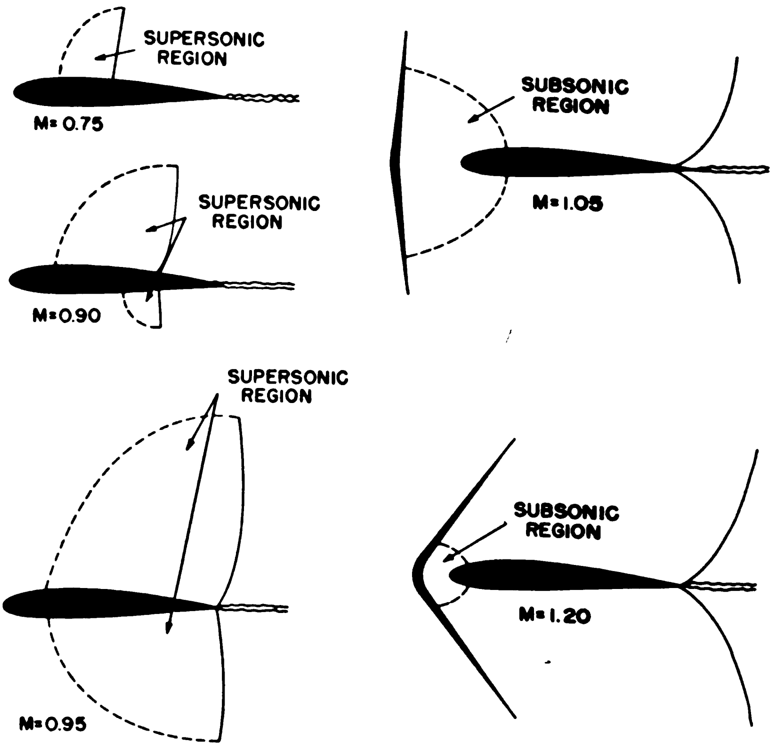


Figure 3–14.—Shock waves on airfoil at various speeds.

shock wave moves back toward the trailing edge. In addition, supersonic airflow develops below the wing, and a shock wave also forms there at the point at which the airflow is reduced to subsonic speed. Finally, when the wing itself reaches supersonic speed, the upper and lower shock waves move all the way back to the trailing edge, and at the same time a new shock wave is produced in front of the leading edge.

ATTACHED AND DETACHED SHOCK WAVES.—The shock wave formed on the leading edge of the wing shown in figure 3–15 is separated from the entering surface by a small area of subsonic air, like the wave produced in front of the blunt object discussed earlier. When the shock wave is separated from an object in this way, it is said to be DETACHED. When first formed, the detached shock wave lies in a plane perpendicular to the airflow. As the speed of the object is increased, the shock wave bends toward it, forming what is known as the MACH CONE. The sharpness of the Mach cone depends on the shape of the object, and is also an indication of the speed of the surrounding airstream. The cone is sharper for wedgelike or pointed objects than for blunt shapes, and it grows increasingly pointed as the speed increases.

Under the right conditions of airspeed and object shape, the shock wave forms on the object itself and is then said to be an ATTACHED SHOCK WAVE. The effects of these conditions are illustrated in figure 3–15. In (A) the formation of a detached shock wave is shown. When the speed of the object increases, the Mach cone becomes sharper and the attached shock wave (B) is formed. The same situation can be achieved by increasing the sharpness of the object, as shown in (C).

COMPRESSIBILITY EFFECTS OF SHOCK WAVES.—Unless the aircraft or missile is designed so that the effects of compressibility are eliminated, many undesirable actions may take place. When normal shock waves appear on the wings, they tend to move toward the trailing edge if the speed of

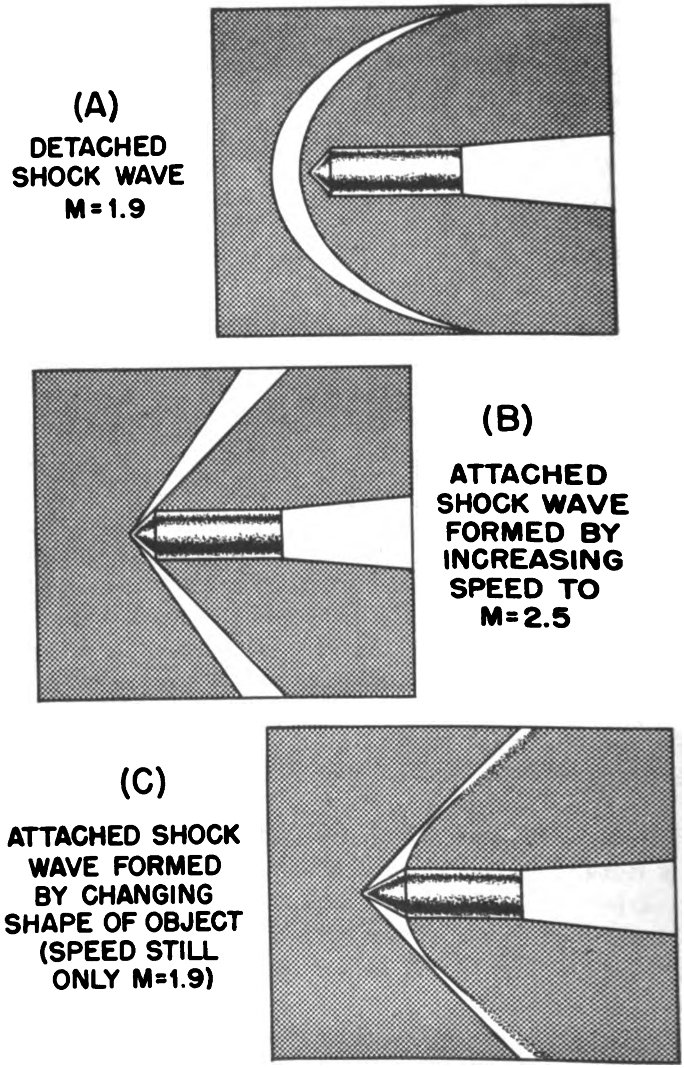


Figure 3–15.—Detached and attached shock waves.

the aircraft is increased, and separation of the airstream occurs immediately behind the shock wave. That is, the air cannot continue to follow the desirable flow pattern normally produced by the wing surface. As a result the airflow tumbles in a random, turbulent motion. When turbulence starts to grow, it makes itself felt in certain ways. For example, rolling motion of the aircraft may result from small differences in wing construction that would be unnoticed at low speeds. Rapid vibrations of the ailerons may occur; and noticeable twisting of the wings may take place.

To avoid these effects, the airframe design of high-speed guided missiles and jet aircraft exhibit several general characteristics. The airframe is provided with a sharp, tapering nose section, and the body is constructed so that there are few if any abrupt changes in contour at which normal shock waves might form. The control surfaces are placed so as to be as free as possible of the turbulence produced by the lifting surfaces—in some cases the control actions are accomplished by moving the entire wing. Wings and control surfaces are very thin and have knifelike edges. This both reduces drag and causes the shock waves that are formed at the leading edges to be of the oblique type. In these the variations in pressure and density are less severe than in normal shock waves which would occur with blunt edges.

Wings for high-speed craft are usually sweptback rather than straight. They have low aspect ratios (the ratio of span to average chord length) thereby presenting a very short and stubby appearance. Several cross section patterns are employed, including the diamond shape, or double wedge, and the biconvex, the latter being the pattern formed by the intersection of two circular arcs. (The characteristics of the various airfoils in use are discussed in a later section.)

Supersonic Flight

Once out of the transonic speed region, the upper limit of which is about Mach 1.2, the airflow over any area of the

aircraft is supersonic in velocity. In this condition the undesirable effects of mixed supersonic and subsonic flow largely disappear, and the passage of air over the airframe surfaces is without turbulence. The variations in pressure which occur are of two principal kinds: compression waves of the oblique shock wave type, and EXPANSION WAVES.

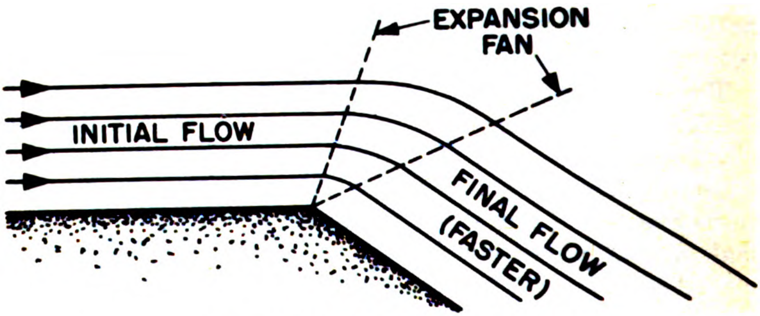


Figure 3–16.—Expansion waves.

Expansion waves differ from normal and oblique shock waves in two respects:

1. The airstream passing through an expansion wave increases in velocity. It undergoes a corresponding decrease in temperature, density, and pressure.

2. The increase in velocity of the airstream passing through the expansion wave is gradual rather than sudden.

LIFT FOR SUPERSONIC AIRCRAFT.—In the section on subsonic flight, the broad general principles of producing lift by cambered wings were pointed out. The thin symmetrical wings used in supersonic flight deserve further explanation because the sharp leading edges employed at these speeds do not produce the same deviation of airflow as their round-nose counterparts.

The thin wing illustrated in figure 3–17 provides lift by means of pressure differences depending on oblique shock waves and expansion waves. The oncoming airstream is deflected by the sharp edge, and then assumes a direction

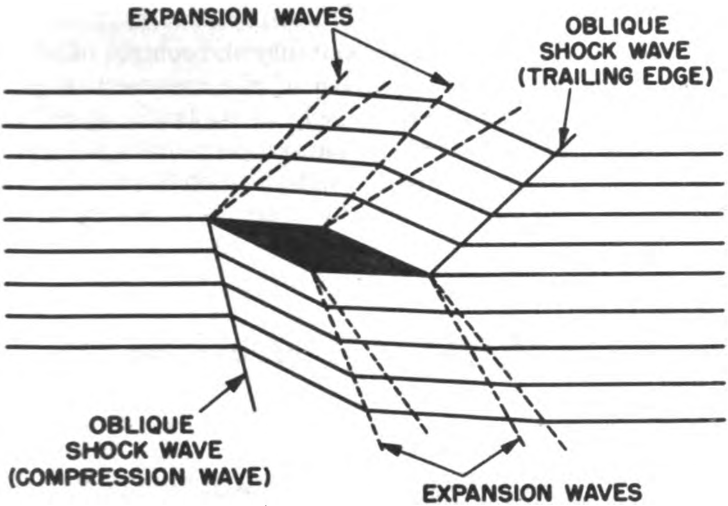


Figure 3–17.—Airflow about supersonic wing.

parallel to the wing. On the upper wing surface the air is speeded up by passing through a series of expansion waves with the result that a low-pressure area is formed on the top of the wing, much as in subsonic flow.

Beneath the wing the force of the airstream (the dynamic pressure), together with the changes occurring in passing through an oblique shock wave, results in the formation of a high-pressure area. As in subsonic flow the difference in pressures on the upper and lower surfaces of the wing results in an upward lifting force.

FLIGHT CONTROL

Missile flight control includes all the processes of attitude and path control. The final process of control, called steering, puts the directing signals into effect by the application of some force which will turn the missile about one of its three axes. This force may be produced by one or more of the following: airfoils, jet vanes, or side jets.

Airfoils

Airfoils are used to provide stability and control of most missiles. The shape—the pattern of the cross section—of the airfoil employed is determined largely by the speed of the missile. Some of the basic patterns are shown in figure 3–18. The contour of subsonic airfoils is similar to that of the conventional aircraft wing, but those used on supersonic missiles are much thinner.

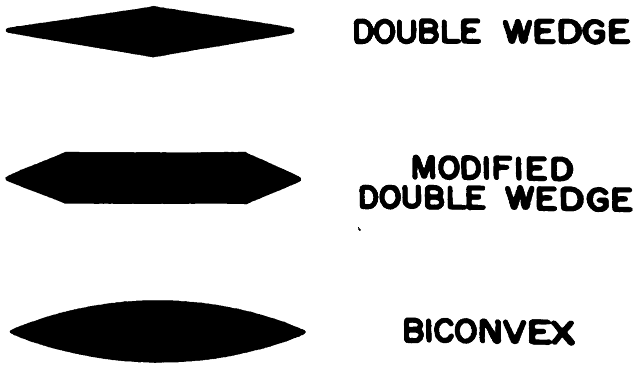


Figure 3–18.—Supersonic airfoil cross sections.

The airfoils used for supersonic flight are symmetrical in thickness cross section and have a small thickness ratio—the ratio of the maximum thickness to the chord length. The DOUBLE WEDGE in the figure has the least drag for a given thickness ratio, but in certain applications it is inferior because it lacks the necessary strength. The MODIFIED DOUBLE WEDGE has a relatively low drag (although its drag is usually higher than a double wedge of the same thickness ratio) and is stronger than the double wedge. Ease of manufacture and good overall performance characteristics make this airfoil the best of presently-known configurations. The BICONVEX, also shown in the figure, has one and one-third greater drag than a double wedge of the same thick-

ness ratio. It is the strongest of the three types shown, but it is difficult to manufacture.

The planform of the airfoils—the outline when viewed from above—may be one of the basic types shown in figure 3–19. As mentioned previously, travel in the transonic and supersonic regions is accompanied by shock waves.

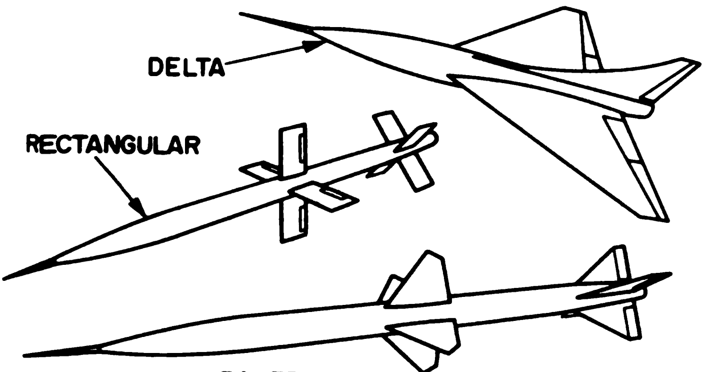


Figure 3–19.—Airfoil planforms.

With the conventional wing plan, which presents its leading edge perpendicular to the direction of motion, shock waves occur at lower speeds than if other planforms are used. The presence of these shock waves on an airfoil greatly increases the drag and subjects the airfoil to extreme stresses. To reduce the effect of these undesirable features, airfoils for transonic and supersonic flight are built in the shape of an arrow or the Greek letter capital "delta" (△) and are swept back or forward. Two types of DELTA planforms and a modified delta, the RAKED TIP, are shown in the figure.

Airfoils are mounted on the airframe in several arrangements, some of which are shown in figure 3–20. The CONVENTIONAL and CRUCIFORM are the most popular tail arrangements; and the HIGH WING and CRUCIFORM WINGS are used for most missiles. Both the INLINE and INTERDIGITAL cruci-

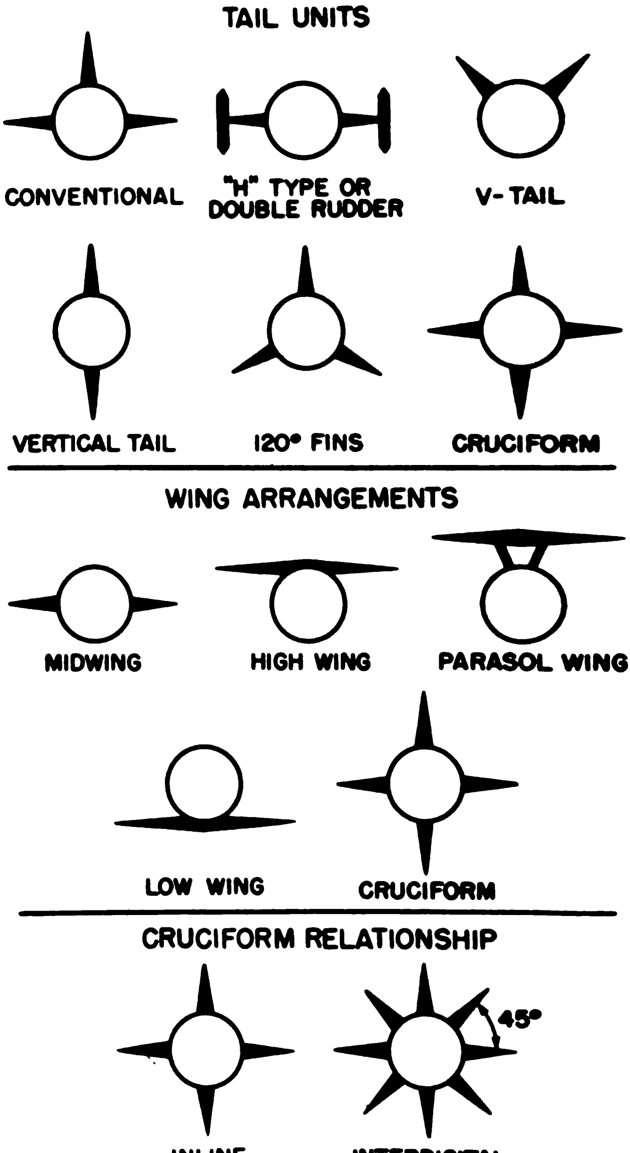


Figure 3–20.—Arrangements of airfoils.

form arrangements are widely used, especially for supersonic missiles.

The two methods of using airfoils to steer a missile are shown in figure 3–21. In (A) of the figure, the airfoil contains a movable section called a CONTROL SURFACE which is deflected so that the force of the airstream turns the missile.

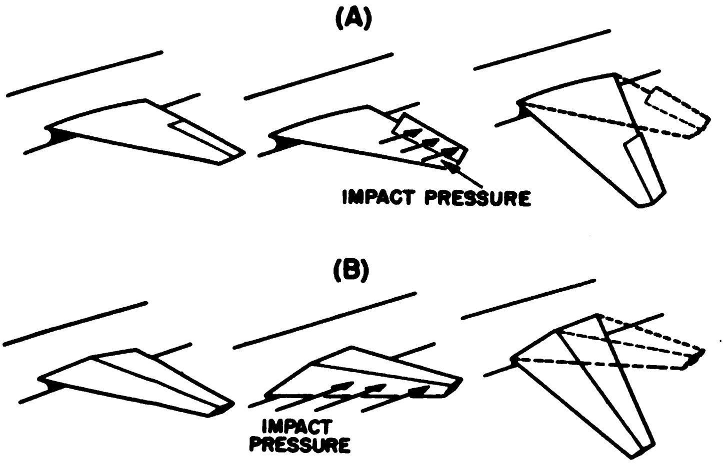


Figure 3–21.—Airfoil control methods.

In the other method, shown in (B) of the figure, the entire air foil is deflected. This type requires less movement to produce the necessary turning force, but as a result a very accurate power unit is required to control its motion. Because the airfoils required by subsonic missiles are very large in comparison with those used for supersonic speeds, it is difficult to move the entire airfoil. For this reason movable sections are used for control of most lowspeed missiles. In some cases the movable sections contain a small control surface, called a TRIM TAB, which is adjusted normally on the ground to compensate for any unbalance or misalinement of the main control surfaces.

Control surfaces are placed on the missile at several locations to provide different types of steering. In the conventional aircraft arrangement, shown in figure 3–22 (A), movable sections of the tail airfoils control pitch and yaw, and control surfaces on the wings control roll. Movement of the RUDDER causes the missile to turn about its yaw axis; the ELEVATORS are moved together to make the missile pitch; and the AILERONS are moved in opposite directions to make it roll. In the cruciform arrangements, shown in (B) and (C) of figure 3–22, pitch is controlled by moving the horizontal surfaces together; yaw is controlled by moving the

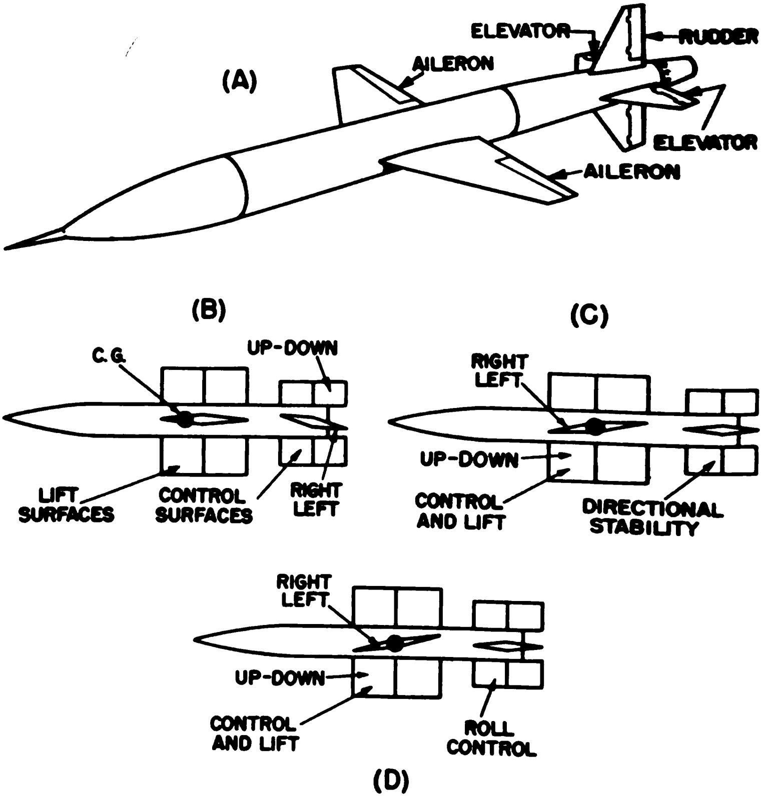


Figure 3–22.—Control surface locations.

vertical surfaces together; and roll is accomplished by deflecting either the pitch or yaw surfaces in opposite directions. If the forward set of airfoils is fixed, and steering is accomplished by the tail surfaces as shown in (B) of figure 3–22, the missile is said to be "tail" controlled. Another type of control is "canard" control, illustrated in figure 3–22 (C) in which the tail fins are fixed and control is provided by the forward surfaces. Other arrangements, such as the one shown in (D) of figure 3–22, may also be used. In the one shown, pitch and yaw are controlled by the forward wings and roll by one pair of tail surfaces.

Airfoil control works efficiently while a missile is in the atmosphere. However, it requires a missile velocity that will create enough air pressure on the surfaces to cause the missile to turn. When the missile moves very slowly or reaches highly rarefied atmosphere, the forces which the control surfaces develop are too small to change the path of the missile. When this happens, it is necessary to use some form of jet steering, such as jet vanes or side jets to control the flight of the missile.

Jet Vanes and Side Jets

JET VANES are similar to airfoil control surfaces in design, but are smaller and are placed in the jet stream of the motor. When moved, these surfaces deflect a portion of the jet gases so that the line of thrust is not directly through the center of gravity nor along the longitudinal axis of the missile. This causes the missile to turn. One disadvantage of this method of steering is that the average life of a jet vane is very short because it is burned out by the tremendous heat from the jet stream. The jet vanes used in the German V–2 lasted, on the average, about sixty seconds.

The disadvantage of using jet vanes may be overcome by the use of several jet motors which are permanently offset, or fixed on the sides of the missile. Jets which are used in this manner to steer the missile are called SIDE JETS. The main requirement for this method of controlling the flight path

is that the jets be capable of being turned on and off rapidly. The turning forces side jets develop remain constant regardless of flight conditions.

Airspeed and Air Density Corrections

When airfoils are used as steering devices, it is necessary to adjust their deflections so that the turning forces they produce will remain constant for varying flight conditions. This is because the lift produced by an airfoil is proportional to the speed and density of the air passing over it, as well as to the angle of attack. At high speeds, or at low altitudes where the air is denser, less movement of the control surfaces is required to turn the missile than at low speeds or higher altitudes.

In some control systems the response of the control surfaces is adjusted by a signal from a pressure gage. This pressure gage measures the dynamic pressure of the airstream which is determined by the velocity of the missile and the density of the air. High speed and high air density produce a high dynamic pressure, and under these conditions the amount of deflection of the control surfaces necessary for a maneuver is decreased.

In other control systems the power units automatically adjust the response of the control surfaces to flight conditions. (With these units the surfaces are not moved an AMOUNT proportional to the directing signal, but are moved until they produce a FORCE proportional to the signal.)

In summary we have discussed the nature of our atmosphere, the basic principles of flight in the regions of subsonic transonic and supersonic speeds, and the control of flight. The information contained in this chapter will help you to better understand the reasoning behind the design of propulsion plants, specific airframe construction and control functions incorporated into our missiles.

QUIZ

1. Missiles flying at an altitude of 3000 feet have more drag than those flying at 45,000 feet because
   a. they are flying through denser air
   b. they are flying through cooler air
   c. because they encounter fewer particles of air per second
   d. they are not aided by the "jet stream"
2. The "jet stream" is encountered in the
   a. upper stratosphere
   b. lower ionosphere.
   c. upper troposphere
   d. upper ionosphere
3. The stratosphere extends from the top of the troposphere to an altitude of
   a. 8 to 10 miles
   b. 40 to 50 miles
   c. 100 to 125 miles
   d. 500 to 650 miles
4. The layer of the atmosphere which has the property of refracting or bending radio waves is the
   a. ozonosphere
   b. stratosphere
   c. troposphere
   d. ionosphere
5. Which of the atmospheric regions accounts for the largest portion of the atmosphere weight?
   a. Troposphere
   b. Ionosphere
   c. Stratosphere
   d. E–layer
6. A missile is capable of what two basic kinds of motion?
   a. Pitch and roll
   b. Rotation and translation
   c. Rotation and yaw
   d. Translation and pitch
7. What are the three axes of a missile about which rotary movements take place?
8. What are the four principal forces acting on a missile in level flight?
9. Between the chord of an aerodynamic surface and the relative wind is an acute angle known as the
   a. chord angle
   b. surface angle
   c. angle of attack
   d. relative wind angle

10. Lift is the result of what two general causes?
    a. Dynamic pressure and pressure of drag
    b. Initial and final dynamic pressures
    c. Weight and pressure of drag
    d. Dynamic pressure and differences in static pressures
11. According to Bernoulli's principle
    a. when air velocity decreases, air pressure decreases
    b. when air velocity increases, air pressure decreases
    c. when air velocity increases, air pressure increases
12. Speeds within the transonic speed zone are between
    a. 0 and 0.75 Mach
    b. 0.75 and 1.2 Mach
    c. 1.2 and 4.0 Mach
    d. 4.0 and 10.0 Mach
13. Sonic speed varies directly with the square root of the
    a. temperature of the air in degrees centigrade
    b. pressure above sea level
    c. absolute temperature of the air
    d. absolute pressure
14. Air is considered to be incompressible when a moving body
    a. moves faster than the pressure wave it causes
    b. moves slower than the pressure wave it causes
    c. moves faster than Mach 1.0
    d. causes great changes in the density of the air flowing over its surface
15. In a normal shock wave
    a. pressure, density, and temperature changes are slight
    b. the wave front makes angles of less than ninety degrees with the axis of motion
    c. the transition of air from supersonic to subsonic flow is smooth
    d. the air always changes from supersonic to subsonic velocity
16. What is the aspect ratio of a wing?
17. If in an airstream there is a gradual increase in velocity with a corresponding decrease in temperature, density, and pressure, which one of the following waves is formed?
    a. Normal shock
    b. Expansion
    c. Oblique shock
    d. Detached
18. Which of the following airfoils usually has the least drag?
    a. Double wedge
    b. Conventional
    c. Modified double wedge
    d. Biconvex

19. The entire airfoil of a supersonic missile moves while generally only a section of the airfoil of a subsonic missile moves because
   a. greater control surface area is needed at supersonic speeds
   b. the entire airfoil of a subsonic missile would be difficult to move since it is larger than the airfoil of a supersonic missile
   c. the airfoils of a subsonic missile require less movement
   d. trim tabs are used on a supersonic missile
20. Which of the following is a disadvantage of jet vane control?
   a. Excessive weight
   b. Overcontrolling
   c. Altitude limitations
   d. Short vane life
21. The main requirement for side jet controlling is that the side jets
   a. be capable of being turned on and off
   b. do not drain the missiles main fuel supply
   c. can be turned in different directions easily
   d. act on a line through the missiles center of gravity

CHAPTER 4

GUIDED MISSILE COMPONENTS

INTRODUCTION

A guided missile is constructed of a number of components; the major ones will be discussed here. The categories of these components may be listed as follows: (1) the airframe, the main structural component which supports all others; (2) the warhead which the missile is originally designed to carry; (3) guidance control components which make the missile a true guided missile as defined in chapter 2; (4) an auxiliary power supply; (5) the propulsion plant or prime mover which causes the airframe and associated parts to be propelled. These five classes of components make up a guided missile. However, because of design features some missiles require help to get off the ground and also to point them in the right direction at the beginning of their flight. Though not an integral part of the missile, the launcher or starting point is an important component of these missiles and its function also will be discussed briefly. Launchers are not themselves equipment that the Guided Missileman must maintain but the operation of the missile while it is on the launcher requires a general knowledge of their construction and operation.

For convenience this chapter is organized so that we start with the overall shell or airframe and then proceed from forward to aft in discussing the various components

of the missile. Because of the amount of information to be covered the discussion of propulsion plants and launchers will be presented in chapter 5.

AIRFRAMES

The airframe of a guided missile consists of the body of the weapon and the airfoils which stabilize it in flight and affect its path. The missile airframe serves the same purpose as the airframe of an ordinary airplane: it carries the necessary components and determines the flight characteristics of the vehicle. But since a guided missile is essentially a one-shot weapon, the body structure suitable for it can be simpler in construction than the corresponding parts of conventional aircraft.

The missile configuration—the shape and size of the fuselage and the shapes and locations of the wings and fins—must meet several important requirements. Among these are the following:

1. The body and airfoils must be aerodynamically suitable for the speed at which the missile is to fly.
2. The entire airframe must be light in weight and sufficiently strong and rigid to withstand the enormous shock loads, vibrations, and accelerations encountered in high-speed flight.
3. The airframe must be easy to assemble and to disassemble, and it must be designed so that the inner components are readily available for removal and repair. The major components should be mounted so that they form independent units, and the missile body should contain adequate room to permit slack in the electrical cables and harnesses so that the inner sections can be removed easily during field maintenance and repair operation.

In most missiles the main body is a slender, cylindrical structure. Several types of nose sections are employed. If the weapon is intended for speeds exceeding that of sound, the forward section usually has a pointed-arch profile in

which the sides taper in lines called "ogive" curves, figure 4-1 (A). In missiles which fly at lesser speeds, the nose is frequently less sharp or is even blunt figure 4-1 (B). In some the forward end is covered by a rounded radome, figure 4-2 (A); in others, the nose section contains the opening which forms one end of the duct required for the jet power system, figure 4-2 (B).

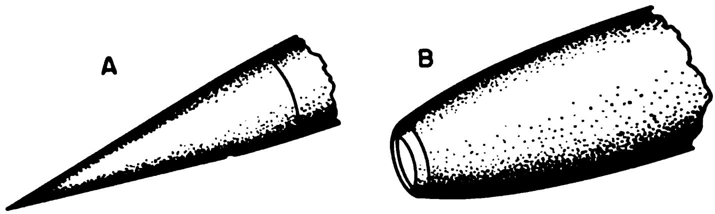


Figure 4-1.—Missile nose sections.

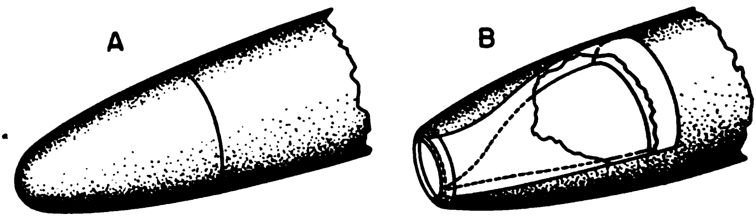


Figure 4-2.—Missile nose sections.

Typical airframes contain a main body which terminates in a flat base. When the contour is slightly streamlined at the rear, the missile is said to be "boattailed." Attached to the body are one or more sets of airfoils which provide lift in some cases, and which control the flight path and increase the stability. The basic types of design which are employed in missile airframes are distinguished principally by the

location of the control surfaces with respect to the missile body. These types are the CANARD, the WING-CONTROL, and the TAIL-CONTROL designs, figures 4-3 (A, B, & C) respectively.

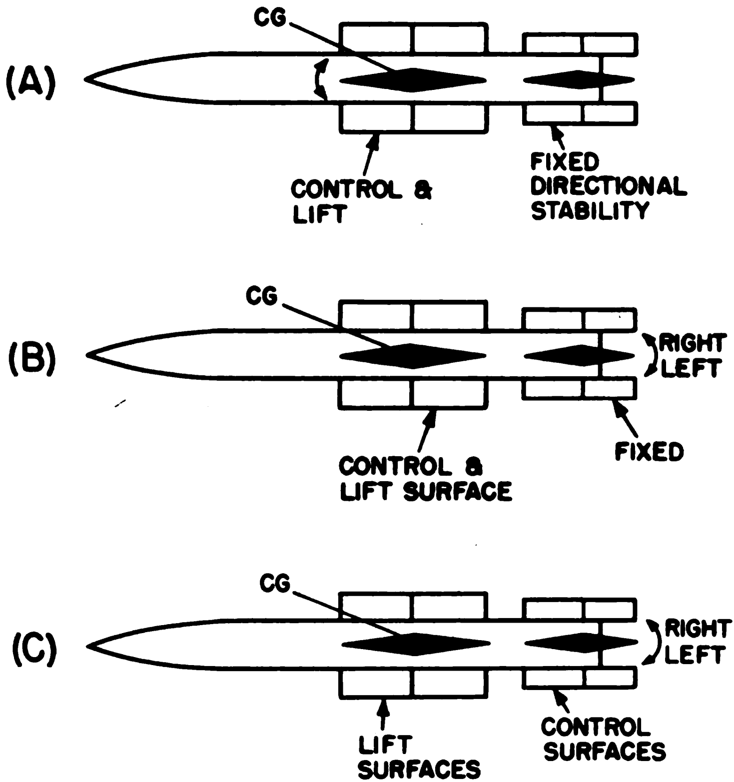


Figure 4-3.—Control surfaces.

For canard airframes small control surfaces are employed which are placed forward of the center of gravity, the point at which the total mass of the body can be considered as being concentrated. Fixed fins, larger than the control surfaces, are mounted on the tail section to increase flight stability.

In the wing-control design the control surfaces are mounted at or near the center of gravity. Larger than in the canard arrangement, the controlling surfaces also provide considerable lift and fixed fins are mounted at the tail section of the missile body. In the tail-control configuration the control surfaces are placed at the rear of the airframe. If wings are included, they are mounted amidships and contribute lifting force but do not control the flight path.

The fuselages of many of the larger guided missiles, such as the surface-to-surface weapons, resemble those of modern aircraft in construction, being based on the SEMIMONOCOQUE structure which is widely used in conventional airframes. The semimonocoque fuselage (the word "monocoque" means "one shell") consists of a metal skin or shell which is internally braced. The strength of the body is provided mainly by the shell, which is reinforced by inner bulkheads, called FRAMES, and longitudinal braces, called STRINGERS.

In surface-to-air missiles the missile body is generally made up of several sections. Each section is a cylindrical shell which is machined from metal tubing rather than a built-up structure with internal bracing. Each body shell contains one of the essential units or components of the missile, such as the propulsion system, the electronic control equipment, the warhead, or the fuze assembly.

Sectionalized construction has the advantage of strength with simplicity and also provides ease in replacement and repair of the components since the shells are removable as separate units. The sections are joined by various types of connections which can be easily made or unmade. An example is the so-called BREECH-LOCK connection, in which the shells contain machined, interrupted threads, allowing the body sections to be joined by making an eighth of a turn. Access ports are usually provided in the walls through which adjustments of the inner components can be made prior to loading the missile on the launcher.

The body sections, the fins, and the wings of surface-launched missiles are constructed from materials which have high ratios of strength to weight in order to insure the necessary strength and rigidity. The airfoils must be thin structures which are required for supersonic flight; and in order to secure the necessary rigidity, these parts are generally machined from solid blocks of metal. Materials frequently used are alloys of aluminum and magnesium.

In the assembled missile, many of the component sections are joined by electrical cables. The connections are made by means of harnesses which run through TUNNEL assemblies. In some of the sections the tunnels are routed internally; and in others, for example, those which house rocket motors or some part of the propulsion system, the tunnels are faired onto the outer skin of the body section.

One or more special connectors called UMBILICAL PLUGS are secured to the missile body flush with the skin. These plugs mate with connectors through which electrical connections are made between the missile components and the launching equipment.

WARHEADS AND FUZES

The prime reason for a guided missile is to carry a destructive force to the enemy in order to deprive him of some advantage or potential advantage. These advantages may be industrial sites, concentrations of troops, points of embarkation, surface marine vessels, or fighter or bomber aircraft. The type of destructive force will be directly influenced by the nature of the target and for this reason we have numerous kinds of warheads or PAYLOADS. The payload contributes nothing to the guidance of the missile and only occupies a section of the airframe. Though it does not influence the guidance section of the missile, it is influenced by this section or by the target depending upon the type of fuzing. You will not be responsible for these "payload" components since a special section of the Gunner's Mate rating or special technicians are charged with this responsibility, but you should know something about them.

Many of the warheads developed for other kinds of weapons can be modified or adapted for use in guided missiles. Among the types of warheads which may be used are: external blast, fragmentation, shaped charge, explosive pellet, rod, chemical, biological and atomic.

EXTERNAL BLAST WARHEADS.—This type of warhead causes damage by means of a high-pressure wave, or blast, which results from the detonation of an explosive substance. When set off by a suitable impulse, the explosive material undergoes a sudden chemical change in which energy is released almost instantaneously. Gaseous products are formed and large quantities of heat are generated. The destructive effect results from the high pressure produced by the rapid heating of the gases.

Blast warheads are very effective against ground targets and have been used in many surface-to-surface and air-to-surface missiles. They are less effective against aircraft, since in the atmosphere the pressure wave dissipates rapidly with distance, and the explosion must take place very near the aircraft to damage it. Large blast warheads can cause great damage to ground installations, and damage occurs hundreds of feet from the point of detonation.

FRAGMENTATION WARHEADS.—These warheads operate by bursting a metal case containing a high-explosive charge. Upon explosion, the container is shattered into hundreds of fragments which fly out at high velocities; and these are capable of damaging targets at considerable distances from the point of detonation. They are effective against aerial targets and are often employed in air-to-air and surface-to-air missiles. Usually the warhead as a whole does not collide with the target but is detonated by the fuze at some distance from it which allows the full destructive effect to be realized.

The factors which influence the destructive action of this warhead are the size of the fragments, their velocity, and the angle at which they are ejected. Fragment size is controlled by the designer by weakening the case at certain points. The fragment velocity is controlled by the shape of the con-

tainer, the ratio of explosive weight to metal, and by the type of explosive used. The angle at which most of the fragments are emitted depends on the shape of the container and the point within it at which the detonation takes place.

SHAPED-CHARGE WARHEADS.—Shaped charges, also called CAVITY CHARGES, make use of the MUNROE EFFECT, in which the explosive power is concentrated by shaping the explosive material. Experiments show that if a regular cavity such as a conical hole is molded into the side of an explosive charge nearest the target, the effect on the target is increased over the effect obtained with the same charge without the cavity. The presence of the hole brings about a concentration of the explosive force similar to the way in which light can be focused into an intense beam by a glass lens.

In the explosion of a shaped charge, a beam of very hot gas (called the JET) is ejected in which the gas particles have an extremely high velocity. If the cavity is lined with some material that can be broken into small pieces or can be melted by the explosion, the efficiency of the charge is greatly increased. The small particles of the liner are carried by the jet, which is thus increased in weight, and as a result it can penetrate a thick target, acting somewhat in the manner of a needle.

When employed in guided missile warheads, shaped-charge explosives have possibilities of great effectiveness against both aircraft and heavily armored surface targets.

EXPLOSIVE-PELLET WARHEADS.—A warhead of this type contains a number of small explosive charges, or pellets, each of which is separately fuzed. When the main warhead is detonated, the pellets are ejected but withstand the force of the explosion and are hurled intact toward the target. The pellets then detonate either on impact or after penetrating the target skin. The total destructive effect combines both blast and fragmentation effects, since blast damage is great when the individual charge is exploded, regardless of whether the explosion occurs at the skin of the target or after penetrating it.

The explosive-pellet is an ideal weapon for use against enemy aircraft. Its full development is dependent upon perfecting a fuze for the individual charges that can withstand the initial blast of the principal warhead while still insuring explosion on or within the target.

There are other types of warheads; however, security requirements prohibit discussing them in this text. You are advised to refer to the appropriate missile manuals which contain the information which you are required to know.

CHEMICAL WARHEADS.—This type may contain either war gases or incendiary materials. Warheads containing gases may liberate any of the well-known types such as mustard gas, lewisite, or some newly developed chemical. The effects produced are either denial of the use of the target area or personnel casualties within the area. Missiles equipped with chemical warheads also serve as possible counterthreats to initiation of gas warfare by the enemy.

The incendiary warhead contains a material that burns violently and is difficult to extinguish and that covers a large area after release from the warhead. Incendiary weapons are useful principally against ground targets.

BIOLOGICAL WARHEADS.—A biological weapon delivered by a missile would contain living organisms capable of disrupting personnel activities in the target area by causing sickness or death to the inhabitants.

ATOMIC AND THERMONUCLEAR WARHEADS.—In this type, destruction and damage result from the processes of atomic fission or fusion. The destructive effects are blast, heat, and liberation of harmful radiation. The detonation results in death, sickness, and the denial of the use of large areas as a result of the release of radioactive elements.

Types of Fuzes

The missile warhead is activated by the actions of one or more fuzes, which fire the warhead after certain conditions have been fulfilled. The type of fuzing employed determines whether the warhead is detonated at a distance from

the target, upon impact with it, immediately following penetration, or at some fixed time after penetration of the target skin.

The most effective type of fuze for a given missile depends upon the nature of the target and the capabilities of the warhead to cause damage. The types often employed in missiles are the IMPACT, GROUND-CONTROLLED, and PROXIMITY fuzes.

IMPACT FUZES.—Impact fuzes are actuated by the inertial force exerted when the missile strikes the target. If detonation takes place at the moment of impact, the fuze is of the NON-DELAY, OF INSTANTANEOUS type.

GROUND-CONTROLLED FUZES.—In ground-controlled fuzing some device is used for measuring the distance from the missile to the target. The control device is not mounted in the fuze but on the ground; and when the proper space relationship exists between the missile and its target, a signal is sent to detonate the fuze from the control point on the ground.

PROXIMITY FUZES.—Fuzes of this type are actuated by the influence of some property of the target and are detonated at a distance which allows maximum damage to take place. Five general classes of proximity (also called VT, or variable-time) fuzes can be distinguished according to the energy to which the device responds. These are radio, pressure, acoustic, photoelectric, and electrostatic fuzes.

Radio fuzes contain miniature transmitters and receivers. In flight, radio signals are radiated, some of which are reflected by the target. At the proper time the action of the reflected waves causes an electronic switch to close and fire the detonator. Fuzes of this kind have been developed to a high degree of accuracy and dependability. They operate effectively both in darkness and daylight and in all kinds of weather.

Proximity fuzes which respond to changes in pressure generally lack the sensitivity and reliability required for guided missile applications, but in some cases they are useful

against surface targets. The problems of the acoustic proximity fuze, which responds to sound, were studied by the Germans at Peenemunde to determine the characteristics of these devices in supersonic missiles. Their wind-tunnel experiments proved that sound waves can be received readily by missiles traveling at speeds in excess of sound velocity. The acoustic fuze has the valuable property of all-weather, day-or-night effectiveness; but it also has the disadvantage that it is subject to local vibration and noises generated within the vehicle as well as to the sound waves by which it senses the target. The Germans also investigated the possibilities of the electrostatic system of fuzing in which the detonating influence is the electric field of the target. Attempts to develop the fuze were unsuccessful—probably because of the variable nature of the electrostatic field surrounding possible targets. Photoelectric fuzes react to external light sources; and ordinarily they are inoperable at night or in conditions of low visibility.

Of these various types of proximity fuzes, the radio system has proved to be the most reliable and effective for missile applications.

GUIDANCE CONTROL COMPONENTS

The control components are the "brains" of the missile and therefore the most important section of the missile to you as a Guided Missileman. It is in this area that most of your efforts will be directed during your career in the Navy as as Guided Missileman. All the professional qualifications for your advancement are based on the operation, maintenance and repair of these components. The subject of guided missile control is a very extensive one comprising many facets of mechanical, electrical, electronic and aerodynamic engineering.

Control systems comprise the missile components that cause the desired changes or corrections in the missile attitude or path. Inputs to these control systems are either attitude control signals from the missile-borne stabilizing

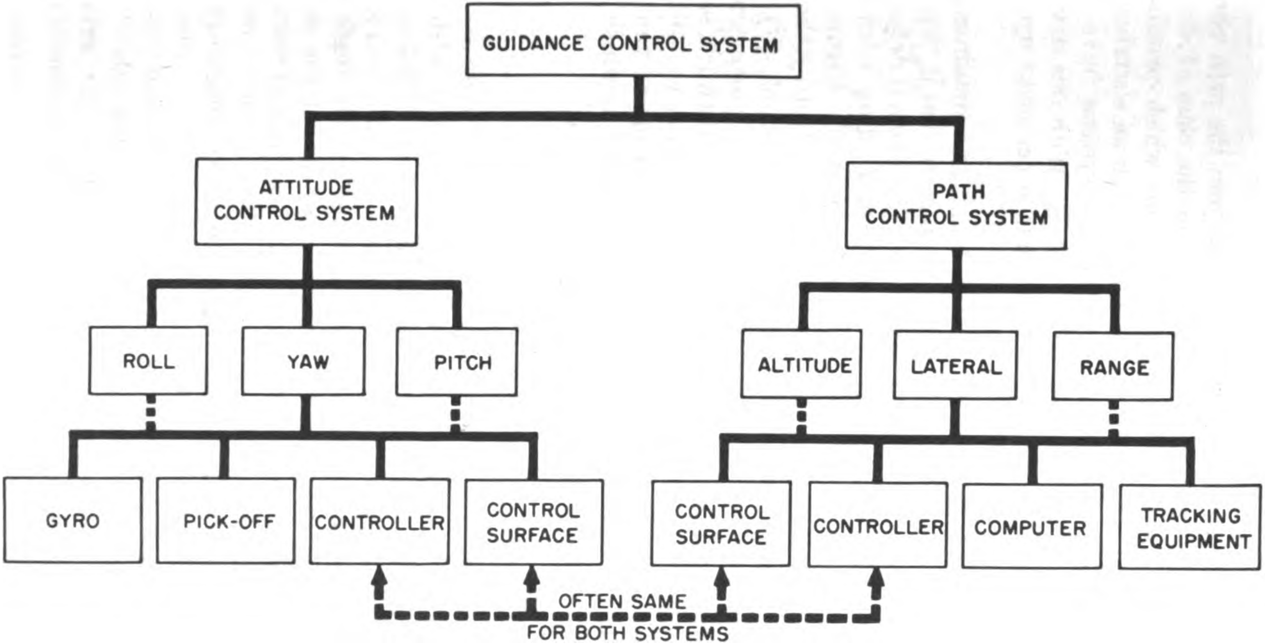


Figure 4-4.—Guidance control system.

reference system or steering signals from the path control system. These control systems are in the class of devices known as servomechanisms, or systems which produce a mechanical output in correspondence with an electrical input signal. You will notice that the systems have been divided into attitude and path control. With this division in mind let us discuss the components which make up each one.

Attitude control refers to establishing and maintaining the proper orientation of the missile in space so that it "knows" up from down and right from left. The general definition of attitude is made more specific by subdividing it into the processes of ROLL, YAW, and PITCH control. Figure 4–4 illustrates that these three senses are controlled by the following components: (1) gyroscope, (2) pick off, (3) controller, and (4) control surfaces. (The controller consists of an amplifier, shaping network, feedback network, servomotors and necessary power.) In this section we will discuss each of these components briefly to acquaint you with the terms peculiar to each and the manner in which each component operates.

The Gyroscope

The guided missile requires a reference in order to orient itself in space and this basic reference, about which all stabilizing control centers, is the gyroscope. This mechanism consists of a wheel mounted on an axle and free to rotate. The wheel and axle are in turn mounted in a set of gimbals. Figure 4–5 illustrates these parts together with the nomenclature peculiar to a gyroscope. The spin axis of the wheel or rotor is through its axle and is displaced 90° from the pivot points of the inner gimbal ring. An imaginary line through the inner gimbal pivot points is the horizontal or input axis. The inner gimbal is pivoted to the outer gimbal ring which in turn is mounted on pivots to the case. These pivot points are displaced 90° from both the spin axis and the horizontal or input axis. An imaginary line drawn

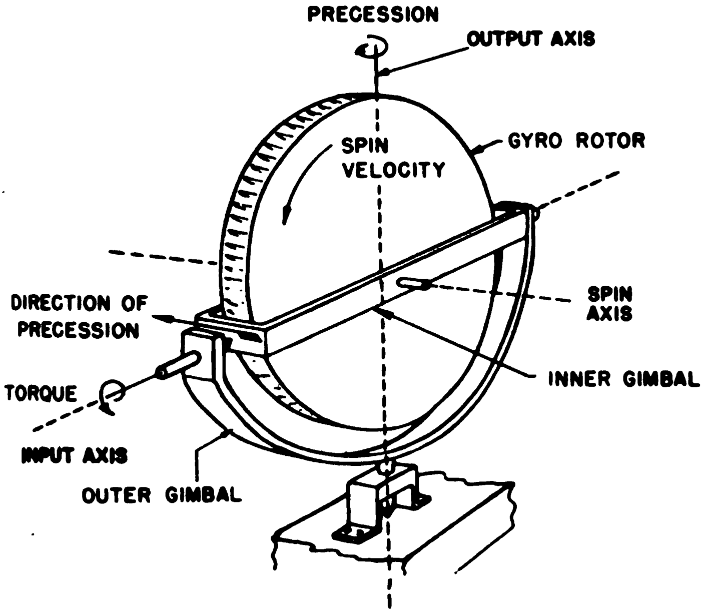


Figure 4–5.—Gyro axes.

through the outer gimbal pivot points represents the vertical or output axis. Each of these axes intersects at a point which is the center of gravity of the entire system. Mounted in this manner the gyro has freedom to turn, tilt and rotate in three planes; hence it derives the name of FREE GYRO.

Although there are three rotational freedoms in the free gyro, it is usually described as a mechanism having only TWO DEGREES of freedom. This may sound confusing; however, by referring to the diagram you will notice that the inner gimbal can revolve about the torque or input axis and precession or output axis only. It cannot turn about the spin axis. The rotation of the gyro rotor around the spin axis is not considered as a DEGREE of freedom.

Another type of gyro, RATE GYRO, is one which, because of its mounting, has but one degree of freedom. Refer to

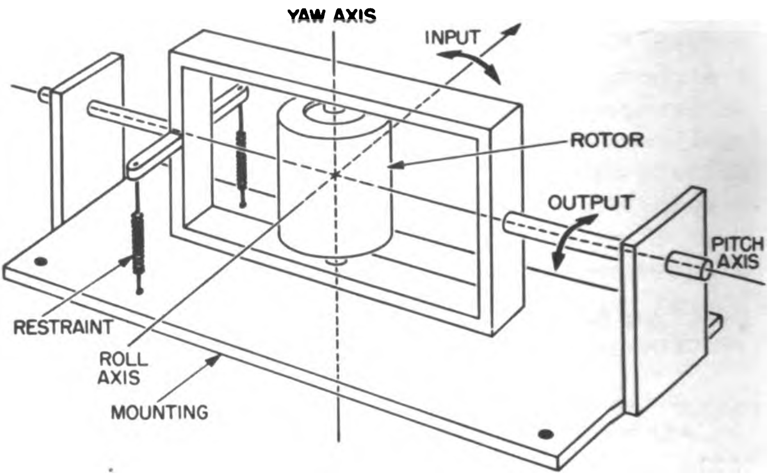


Figure 4–6.—Rate gyro.

figure 4–6. The degree of freedom illustrated here, though restricted by the restraining springs, is about the pitch axis. The springs provide a stress on the gimbal to insure a linear relationship between the input and output forces.

The gyro possesses two properties which make it useful as a reference. The first of these is RIGIDITY IN SPACE. This means that the spinning rotor will remain parallel to the plane in which it is spinning provided it is not acted upon by an external force or torque. As a result the rotor axle or spin axis will remain fixed in space. For example, if the spin axis were pointed at a particular star, the axis would continue to point at the star regardless of the actions of the missile carrying the gyro. The degree of rigidity in space is dependent upon the weight of the rotor and the speed at which it rotates. The factor of weight may be increased by concentrating the weight near the circumference of the rotor. See figure 4–7.

Another property of the gyro is that of precession. Precession, by definition, is the reaction of any spinning body to any torque that tends to change the plane of its spin axis.

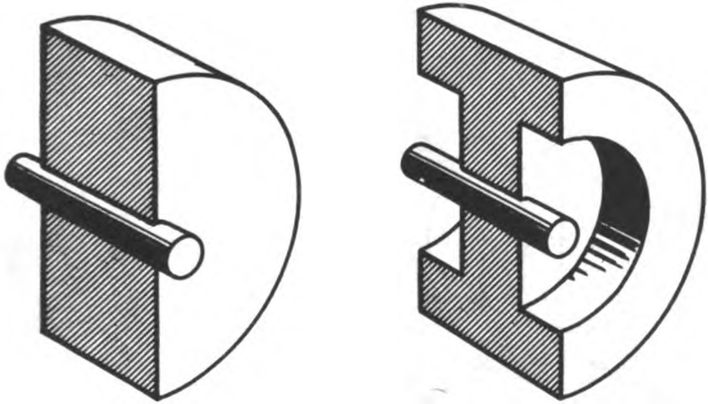


Figure 4–7.—Concentration of weight at circumference of gyro rotor.

Any spinning body has three axes; the spin axis, about which the body spins; the torque axis, about which a torque may be applied; and the precession axis, about which the body will precess when the torque is applied. These axes are all mutually perpendicular. There are two things about precession and the amount or rate of precession. The direction of precession is dependent upon the direction of spin and the direction of the applied torque, and will ALWAYS be in such a direction that the spin axis will try to align itself with the torque axis and that the direction of spin will be in the same direction as the applied torque. For a further explanation, refer to figure 4–8.

In (A) of figure 4–8 the wheel or rotor is spinning clockwise about the axis CC (the spin axis). We apply a force at point Z which tends to turn the wheel about the BB axis. The BB axis is the torque axis in this case. The spin axis will turn or rotate until the applied force is removed or until the spin axis is in line with the torque axis. This is represented in figure 4–8 (B) by showing the spin axis displaced 90° from its original position.

The rate of precession is dependent on the torque applied and the rigidity of the spinning rotor. The direction of

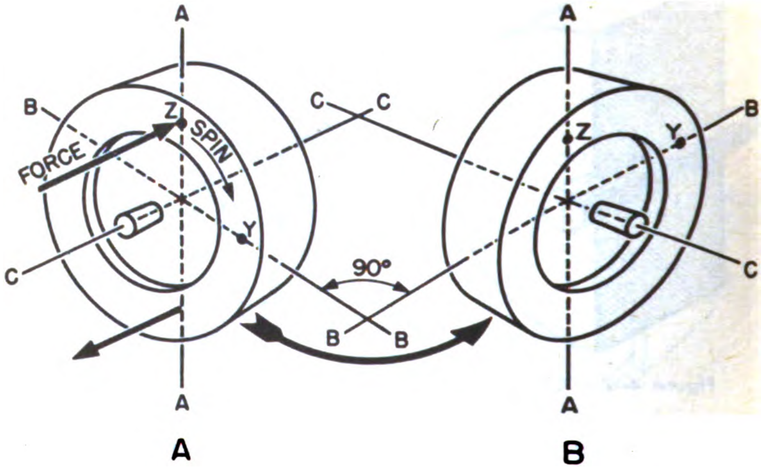


Figure 4–8.—Precession effects.

precession, as a result of applied torque, is dependent upon the direction the rotor is spinning. A force applied causes the rotor to move away at a point 90° around the rim in the direction of spin. Refer again to figure 4–8 (A). The force is applied at point "Z" but point "Y", 90° removed in the direction of spin, moves away.

The methods of use of both the free and rate gyros are explained in chapter 11 of this text.

In order to derive intelligence as a result of gyroscopic precession, we need a device to convert the mechanical displacement of the gyro gimbals into an electrical signal. This device is called a PICK-OFF. It may be an inductive, capacitive, resistive type or some other form such as a light ray. One of the requirements of this device is that its physical connection to the gyro be as frictionless as possible in order that no unwanted torque is introduced to the gyro. Figure 4–9 shows a very elementary type of pick-off and is for illustration only. Referring to the figure you will notice

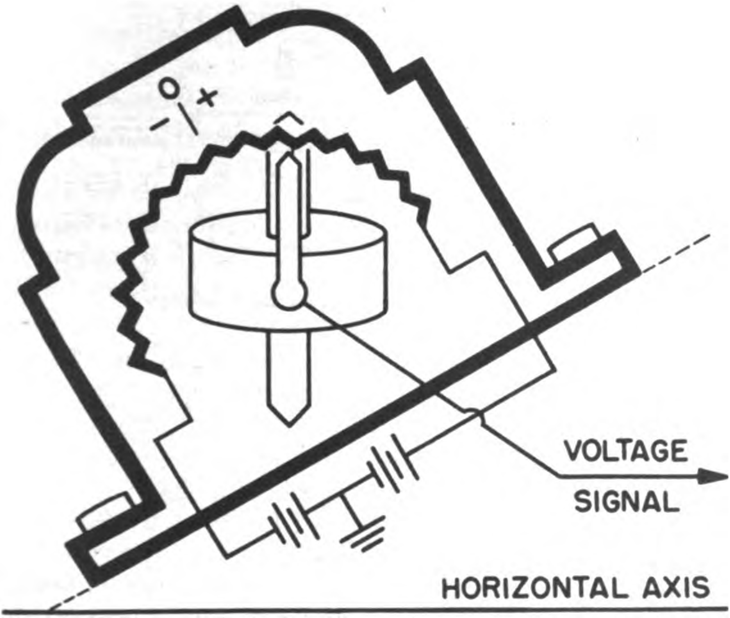


Figure 4–9.—Simplified pick-off.

that as the "missile" tilts the gyro spin axis remains fixed in space; the potentiometer is moved across the wiper arm by this action and a particular amount of voltage is "picked off." This voltage may be calibrated to indicate the amount of tilt or be sent as a signal or order to another device, THE CONTROLLER, to be used by it. PICK-OFFS will be discussed more in detail in relationship to circuitry in a later chapter.

Another method of deriving intelligence from gyroscopic precession is by using a synchro generator and a control transformer. See figure 4–10. The rotor of the generator is physically connected to the precession axis of the gyro. As the gyro precesses in one direction or another the rotor of the generator is moved from the position of zero error.

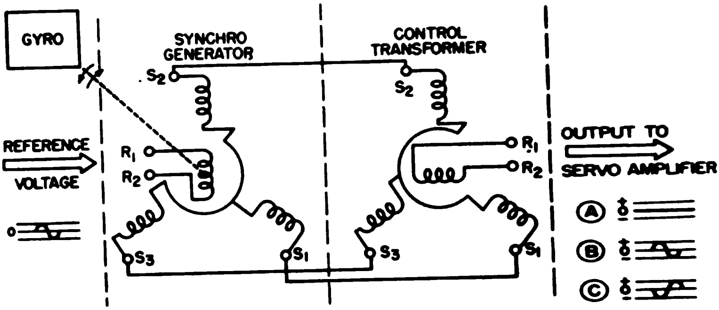


Figure 4–10.—Use of synchro and control transformer.

By transformer action a voltage is generated in the S1, S2, and S3 windings and transmitted to the corresponding winding of the CT (control transformer). A reference voltage (a-c) is impressed on the rotor of the generator and also on the servo amplifier to be discussed later. The output of the control transformer is taken off the rotor leads. The phase of this voltage represents the direction of gyroscopic precession and the amplitude represents the amount. Refer again to figure 4–10. As shown in figure 4–10A, the output is zero for the positions shown. Should the rotor of the generator be turned counterclockwise, the output of the CT would be as shown in 4–10B. And, conversely, if the generator rotor is turned clockwise, the output of the CT would be as shown in 4–10C. To understand the principles of the correlation of synchros and control transformers fully, refer to chapter of *Basic Electricity*, NavPers 10086.

The CONTROLLER as used in a guided missile is the device which causes the physical movement of control surfaces or the actuation of other control devices in response to an input signal. The entire system may be termed a servomechanism. This servo or servomechanism contains an error detecting device which produces the error control signal, that is, the difference between the input signal and a signal which represents the output motion. The term ERROR SIGNAL in guided missile terms represents the difference between servo

input and output. Included also in the servomechanism is the servocontroller which consists of a power source, a servo amplifier, a servo motor and connecting linkages. The input to the servo controller is the error signal from the error detecting device. To complete this closed loop servomechanism, a feedback circuit is included. This feedback circuit, or antihunt circuit, prevents oscillation or overtravel of the control surfaces. A simplified diagram of a servomechanism is shown in figure 4–11. The fundamental concepts of servos will be found in *Basic Electricity* (NavPers 10086) and will not be taken up in this text. The grouping of the components into a particular system are covered in chapter 11 of this course.

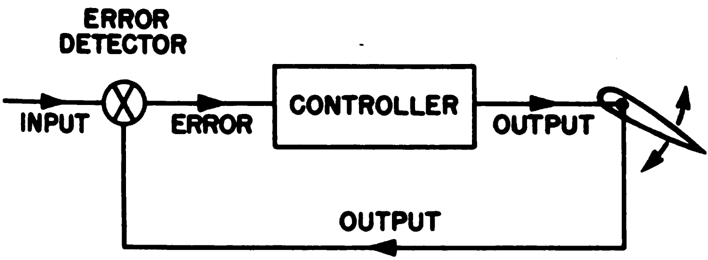


Figure 4–11.—Schematic of simple servomechanism.

The output of the error detecting device in a missile is a voltage which represents both amount and sense of error. Of itself this voltage does not have the power to do work. Depending on the method of actuating the control surfaces by servo motors, servo valves or other devices, this error voltage must be amplified and conditioned for this use. The servo amplifier accomplishes this task. Basic amplifier theory is covered in NavPers 10087, *Basic Electronics*, and because of the many types of amplifiers which may be used to convert this error signal to usable values, it is not feasible to cover them all here. We will, however, cover one simple amplifier which may be used to run a low power d-c servo motor in order to acquaint you with a general method

of utilizing the error voltage. The servo amplifiers used with specific missiles are covered in the instruction manuals associated with each missile.

The simple amplifier which we shall analyze converts the alternating error signal into a pulsating d-c voltage. Refer to figure 4–12. The error signal is impressed on the primary winding of the transformer T–1. This voltage will either be in phase or out of phase with the reference voltage impressed on transformer T–2 which is the plate supply voltage for V_1 and V_2.

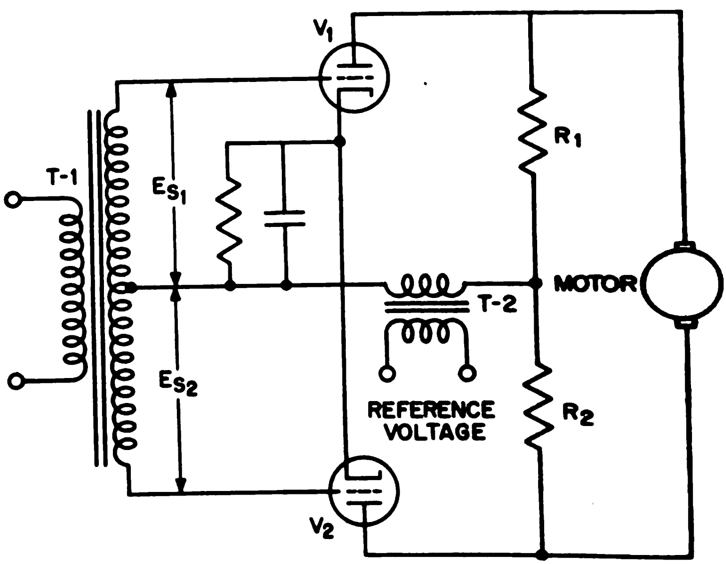


Figure 4–12.—Simple amplifier circuit for servo motor.

The conditions which exist in the quiescent state are as follows: V_1 and V_2 each conduct during the positive cycle of the reference voltage. The voltage drop across the plate load resistors R_1 and R_2 is equal and opposite; therefore, there is no output. If we cause a signal voltage to be im-

pressed across the primary of T–1 which is in phase with the reference voltage, it will cause the input to the grid of V_1 ($ES1$) to be in phase with the plate voltage and the input to the grid of V_2 to be out of phase with the plate voltage. This will cause a decrease in the bias of V_1 with a resultant increase of plate current and decrease of voltage across R_1. Also, the bias of V_2 will increase with a resultant decrease of plate current flow and an increase of voltage across R_2. We now have an unbalance of voltages in the resistor network consisting of R_1 and R_2. The output voltage will be the algebraic difference of these two voltages. When the signal is out of phase with the reference voltage, the converse of the above analysis holds true and the output will be of opposite polarity causing the motor to reverse direction. The direction of motor rotation is a change of phase. The speed at which the motor will rotate depends on the amplitude of the error voltage resulting from the amount of error of the gyro.

In order to eliminate hunting or over travel in the servo system, an antihunt device is incorporated into the servomechanism. This antihunt device usually acts to slow up the servo motor just before it reaches its stopping position. The inertia of motion of the motor and the load is therefore very low, and overtravel is eliminated. The antihunt device works the same as a degenerative feedback circuit in an amplifier. Degenerative feedback is defined as a voltage fed back from the output to the input 180° out of phase with the input signal voltage. This feedback may also be called negative feedback or inverse feedback; they all mean the same: a voltage 180° out of phase with the input. The methods of introducing this degeneration to the amplifier will be discussed in a later chapter.

In summary, in this section so far we have briefly covered gyros, the main brain of the missile; a method picking off the intelligence of gyroscopic precession; the transmission of this intelligence by electrical means to the servo amplifier; the amplification of error signals; and finally the feedback

voltage to control the error voltage and prevent oscillation of the control surfaces. These elements are used to control the attitude of the missile. We shall next concern ourselves with the method of steering or controlling the path of the missile in flight.

MISSILE SYSTEM FUNCTIONS

The preceding explanations have shown how the missile senses direction along the three axes about which it might rotate. These were right or left about the yaw axis, up or down about the pitch axis and clockwise or counterclockwise about the roll axis. The next step is to guide the missile from the launcher to the target. The process of guidance at this stage may be divided into four functions which are tracking, computing, directing and steering. By these four functions the missile is kept on the desired trajectory. There is a close relationship between these functions and the attitude control systems previously explained. Lateral control receives a signal either from within the missile or from an outside source and actuates the yaw control system. These two systems differ only in the source of the signal received. The attitude control system is integrated with pitch control and causes the missile to climb or dive. Again the two differ in the source of the signal. Range control is associated with the propulsion system and may control the time of flight, the pitch, the self destruction circuits or all three of them.

Tracking is the process of determining the location of the missile with respect to the launcher, the target, the trajectory (path of flight), or some other reference or a combination of two or more of these. The different methods of tracking are explained here in relation to various guidance systems. Since the trackers are missile components carried in the missile or located on the surface, we will only concern ourselves with them. Systems of guidance are covered in chapter 7.

In the TERRESTRIAL REFERENCE SYSTEM there are several types of tracking components. One type is the magnetic compass which continuously points to the north magnetic pole. By setting the zero position of the gyro to the desired course, a signal will be generated if and whenever the missile deviates from this heading. The error signal will be fed to the controller causing the missile to return to the predetermined course. Another terrestrial reference type is a magnetic field measuring device. This device causes the missile to follow a line of constant magnetic intensity. These systems result in trajectories that are essentially east-west.

In RADIO NAVIGATION SYSTEMS devices in the missile generate error signals if there is a time difference between the received pulses generated by two radio transmitters. This error signal actuates the controller to bring the missile back on course. The process is much the same as that used in the Loran type of navigation.

CELESTIAL NAVIGATION SYSTEMS have star and tracking telescopes carried in the missile. They are capable of locking on a star and tracking it continuously day or night. By observing and accurately clocking the stars, the position of the missile can be determined. These trackers are used for long range missiles because the accuracy of the system is independent of range.

Ground radars similar to fire control radars are used to track relatively short-range missiles. In the beam rider system a radar beam tracker within the missile is employed. This tracker detects in which quadrant of the conical scan the missile is located. This information is translated into an error signal and sent to the controller causing the missile to return to the center of the beam. Homing system radars within the missile track the target and cause the missile to guide itself along a collision course with the target. Radar beacons are radar frequency receiving and transmitting stations located in the missile itself. They are dormant

until such time as they are triggered by an external signal. The ground radar signal is received, amplified, and causes the triggering of the beacon transmitter. The beacon transmitter returns a signal to the radar which is strong compared to the echo received from the missile itself. This device permits long range tracking of small missiles which might otherwise be lost as a result of the weak echo signals. The best method of tracking known to us at the present is the radar system. Radar is not hampered by weather, darkness or the error of human perception. In addition, it has a relatively long range.

Computing Function

COMPUTING is the process of calculating the directing signals for the missile by using the intelligence supplied by the tracking devices. This computation may be done on the ground, in the missile or in both locations. An example of this is shown in figure 4–13. The aircraft is moving on a certain course at a certain speed. The missile, after launching, also has these components. By use of radar both the missile and the target are acquired and tracked. The time rates of change in bearing, in range, and in elevation for both are sent as tracking information to the computer. By integration of these two sets of information a collision course is worked out in the computer and this information is sent to the missile as error signals which are applied to bring the missile on a collison course.

For homing systems computers consist mainly of networks that take the error signal from the missile radar or infrared detector and feed it in proper form to the steering components which cause the missile to correct its error and remain centered on the target. For moving targets these networks introduce a lead angle to prevent the missile from being required to maneuver radically as it approaches the target. This is required because of the acceleration limits imposed on the missile because of structural design.

In celestial navigation systems a computer compares the

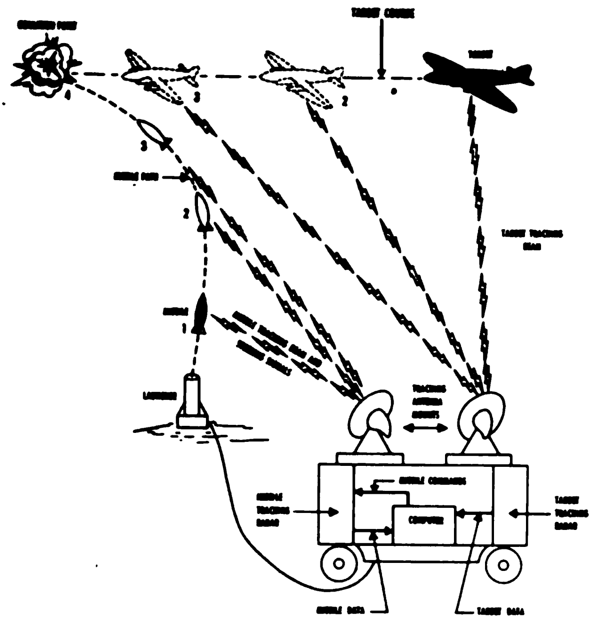


Figure 4–13.—Computation external to the missile.

observation of the star tracker with an accurate time source and the mechanically or electrically recorded navigation tables. The computer determines the instantaneous position of the missile and then generates the proper signals to steer the missile toward the target. This is a continuing process during the time of flight.

Program devices initiate certain actions at a specific time, at a specific speed or at a given distance. These are considered computing devices also. A constant speed motor gear to a camming device acts as a timer. When each cam reaches a certain position of rotation it causes a microswitch to open or close which initiates some action within the missile. Coded punches in tape such as used in a teletypewriter or coded information on a magnetic tape are used to program a missile. Distance is measured by a device called an integrating accelerometer which can cause specific

actions to occur when a preset distance is covered or when a specific speed is attained.

Directing Function

DIRECTING is the process of sending the computed signals to the missile. This is accomplished by use of radar or radio pulses sent to a receiver in the missile. The directing may also be accomplished within the missile itself by means of electric, hydraulic, or pneumatic means. In the radio navigation systems two transmitters send out pulses simultaneously. When received by the missile, an error signal is generated if there is a time difference between the signals. In this manner the missile is directed to return to a course which will cause it to receive these signals with no time difference. In a radio command system the missile is directed to fly right or fly left or fly up or fly down by amplitude or frequency modulated signals from a radio transmitter. Different tones of amplitude modulation control each of the four separate actions. When using a radar beam to direct, the missile intelligence is superimposed on the beam. This type of directing not only tracks the target but also tells the missile how to move in order to intercept the target. Chapter 6 of this text will cover the fundamentals of the radar guidance systems in more detail. Steering devices have been covered previously in chapter 3.

A complete control system must include devices to insure both attitude and path control. The two control systems are closely interrelated and may use components which are common to each other. For example, a single controller may be substituted for the two indicated by figure 4–4. The same is true for the control surfaces. No one system may be classed as the ultimate. The components described here are representative of types employed in specific systems. Many missiles may use two or more of these systems resulting in a multiplicity of components. Specific missile manuals described the particular components used.

QUIZ

1. The airframe of a guided missile differs from the airframe of an ordinary aircraft in which one of the following respects?
   a. The missile body and airfoil must be aerodynamically suitable for the designed speed.
   b. The missile airframe must be light in weight.
   c. The missile airframe can be of relatively more simple construction.
   d. The missile airframe must be strong and shock resistant.

2. Of what does the guided missile airframe consist?
   a. Missile framework and aerodynamic surfaces
   b. Framework and jet motor
   c. Aerodynamic surfaces and guidance control system
   d. All of the missile including the internal parts

3. What are the three basic types of airframes with reference to the location of the control surfaces?

4. The control surfaces of a canard airframe are located
   a. forward of the center of gravity
   b. at or near the center of gravity
   c. aft of the center of gravity
   d. near the tail

5. The principal strength member in semimonocoque airframe construction is the
   a. frame
   b. stringer
   c. inner bulkhead
   d. shell

6. The principal advantage of the sectionalized construction generally used in surface-to-air missiles is
   a. the added strength provided by internal bracing
   b. not all the essential missile components are contained in one body shell
   c. that access ports are not required
   d. strength combined with simplicity that permits easy repair

7. What are the plugs for electrical connections in missiles usually called?

8. External blast warheads cause damage primarily by means of
   a. heat waves
   b. pressure waves
   c. fragmentation
   d. very hot gasses

9. The principal problem in perfecting an explosive-pellet warhead is
   a. developing a workable fuze for the individual pellets
   b. determining the optimum size of the individual pellets
   c. developing a suitable contact fuze for the warhead
   d. shaping the initial blast of the principal warhead

10. What are the three types of fuzes commonly used in guided missiles?

11. Which of the following types of proximity fuzes appears to be most reliable and effective for missiles under all conditions of operation?
   a. Pressure
   b. Electrostatic
   c. Photoelectric
   d. Radio

12. Missile guidance control systems are normally subdivided into
   a. pitch and yaw control systems
   b. altitude and path control systems
   c. ·roll and altitude control systems
   d. yawl and pitch control systems

13. What are the two properties of a gyro which make it useful in a missile control system?

14. Which of the following types of pick-off devices can be used to derive intelligence from gyroscopic precession?
   a. Inductive device
   b. Capacitive device
   c. Light ray device
   d. Any of the above

15. A servomechanism in a guided missile is
   a. a self-contained power supply for the gyroscope
   b. a device for maintaining constant fuel flow in liquid rocket engines
   c. an error detecting device which produces the error control signal
   d. a self-contained power supply for the synchro generator

16. What device in the servomechanism system prevents over travel or over correcting?

17. The accuracy of which of the following missile tracking systems is independent of range?
   a. Terrestial reference system
   b. Celestial navigation system
   c. Radar tracking system
   d. Radio navigation system

18. What is the process of calculating directing signals for a guided missile using the information supplied by tracking called?

19. What are the four things necessary for successful missile guidance?
    a. Tracking, computing, aerodynamic stability, and supersonic speed
    b. Supersonic speed, booster, tracking, and directing
    c. Tracking, computing, directing, and steering
    d. Computing, radar beam, booster, and steering

20. Missile radar beacons increase maximum tracking range by
    a. returning a separate signal to the tracking radar when triggered by it
    b. presenting a more reflective surface for the tracking radar
    c. amplifying the radar echo of the target
    d. re-transmitting radar pulses as long wave radio signals

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CHAPTER 5

PROPULSION PLANTS AND LAUNCHERS

In order to be effective, a guided missile must travel at a high rate of speed. This characteristic serves two purposes, the first of which is to reduce the effectiveness of enemy interception and reduce the time available to countermeasure the control system. The second purpose is to enable our own missiles to destroy the enemy missiles and aircraft at a point beyond the lethal range of their armament. The jet propulsion engine is the only feasible power plant capable of propelling a guided missile at supersonic speeds to serve the two purposes just mentioned.

The basic principle of jet propulsion will be discussed prior to particular jet engine types. Initially, jet propulsion is the result of ejecting matter from within the propelled body in order to create momentum.

There are two methods by which we can produce thrust: by mechanical means (pumps or fans), and by thermal means (chemical reaction). The mechanical jet is exemplified by a rotating lawn sprinkler. As the water leaves the nozzles its velocity is increased thus causing the sprinkling arms to rotate. Another example of the mechanical jet may be found in nature. The squid draws water into itself and then by contraction of its muscles forces this water rearward through a small opening at an increased velocity thus propelling it forward. Mechanical jets have had little appli-

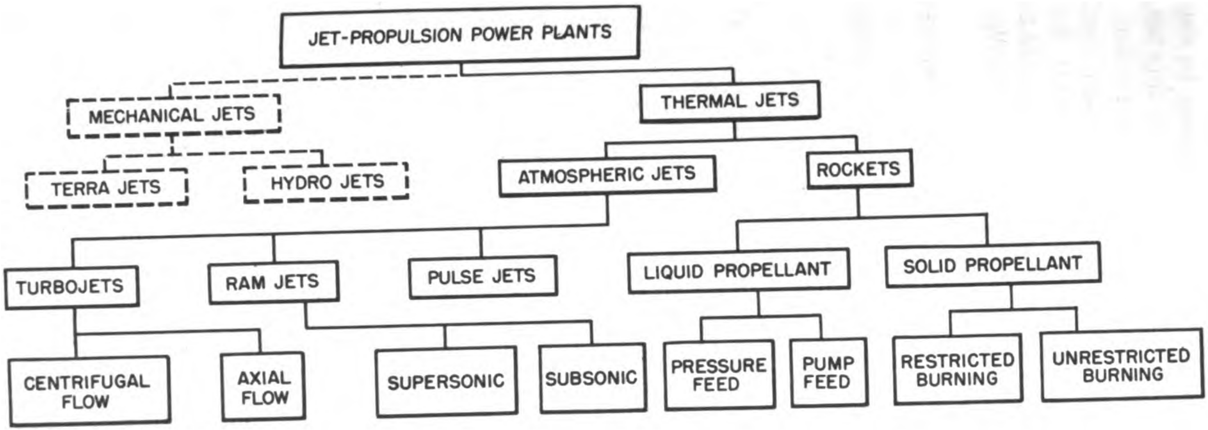


Figure 5–1.—Classification of jet power plants.

cation in the field of guided missiles to date. Therefore, they will not be discussed further in this test. Figure 5–1 shows a number of types of jet propulsion. The various jet power plants shown under the general heading of atmospheric jets and rockets will be discussed in this test. It will be necessary to discuss some of the principles and define some of the terms used in explaining these principles before taking up the engines themselves.

A jet engine does NOT rely upon the medium in which it travels in order to obtain its thrust. The thrust is attained by increasing the momentum of the working fluid in the engine which, in missile engines, is the exhaust gas. Sir Isaac Newton's third law of motion states that "for every action there is an equal and opposite reaction." In this light jet engines may be called reaction motors. This is a broad statement for any body which is self-propelled and moves in a fluid works on the reaction principle. The fact that the working fluid is within the engine itself differentiates this particular reaction from the others.

The application of a force for a definite period of time is called impulse. Impulse may be stated mathematically as F t, where F is equal to the force and t to the time that this force is working on the body. An unbalanced impulse working on a body will cause a change in the momentum of that body. In an ideal situation, where friction forces are neglected, the change in momentum will numerically equal the impulse. The term impulse is one of the rating factors of a rocket motor, i. e. if the motor runs for two seconds while developing 50,000 pounds of thrust, the impulse is $Ft = 50{,}000 \times 2 = 100{,}000$ pound secs.

The term THRUST which has been used frequently should be defined. It is a force tending to produce motion in a body or to alter the motion of a body. This quantity is usually measured in pounds but may be measured in tons if the engine is sufficiently large. The thrust is NOT a direct measure of work or power, since work is a measure of a force acting through a distance and power is the time rate

of doing work. A jet engine which is not moving covers no distance and hence does no work nor does it produce power.

Jet engines must produce large quantities of gas under high pressures and temperatures, and must provide a means of converting its heat energy into kinetic energy. To accomplish this all jet engines have the following components:

(a) A combustion chamber.

(b) A fuel supply system.

(c) A nozzle or exhaust pipe.

Large quantities of high-pressure and high-temperature gases are produced by the chemical reaction of a fuel and oxidizer in the combustion chamber of a jet engine. The heat energy thus made available is converted into kinetic energy by means of an expansion process through the nozzle or tail pipe.

It should be remembered that the rocket is the only jet engine capable of operating outside of the atmosphere because it is the only jet engine which carries its own oxidizer. Rockets may be divided into two classes, solid propellant and liquid propellant, each of which has its own applications and limitations. The more important characteristics of all rocket engines are:

1. The thrust of a rocket is nearly constant and is independent of speed.

2. Rockets will operate in any fluid medium or in a vacuum.

3. Rockets have relatively few moving parts.

4. Rockets have a very high rate of propellant consumption.

5. Burning time of the propellant in a rocket is short.

6. Rockets need no booster. They have full thrust at take-off; therefore, when rockets do employ boosters it is for the purpose of reaching a high velocity in a minimum of time.

The chamber of a solid propellant rocket engine contains a charge or grain of solid propellant which may consist of

an oxidizer and fuel mixture. One form of solid-propellant burning may take place on a relatively large burning surface area on the propellant (or grain, as it is called) at once. This type of rocket, called an UNRESTRICTED BURNING rocket, is characterized by a very short burning time (.05 to 5 seconds) and a high thrust. These rockets are used for artillery rockets and rockets called boosters, to boost missiles to a high velocity.

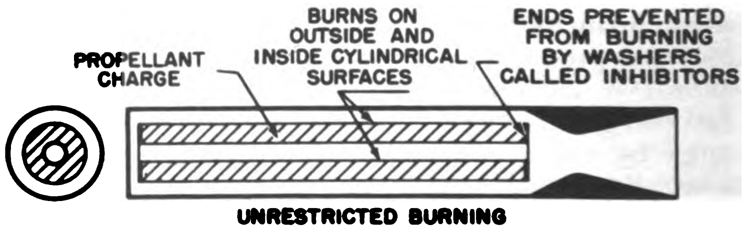


Figure 5–2.—Unrestricted burning rocket.

Another form of the solid-propellant rocket is a RESTRICTED BURNING rocket. (See fig. 5–3.) In this rocket the grain of propellant is allowed to burn only on relatively small surface areas; that is on one end only. This increases the time required to burn the grain and so liberates the energy more slowly. This gives a lower thrust for a longer period of time (5 to 40 seconds). Some of the uses for this type of rocket are JATO units, artillery rockets, and sustaining rockets for guided missiles.

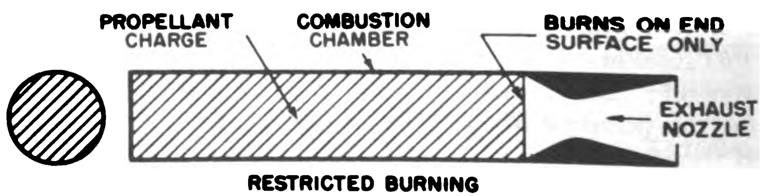


Figure 5–3.—Restricted burning rocket.

Solid-propellant rockets are relatively simple and easy to manufacture, but have a few undesirable characteristics. For instance, most solid propellants require pressures of 750 to 2000 pounds per square inch in order to sustain efficient combustion, and the exhaust gases reach temperatures from 4000 to 5000 degrees Fahrenheit. These high pressures and temperatures require large, heavy casings to withstand them, thus limiting the practical size of solid-propellant rockets to about one ton and under. Another weakness is their susceptibility to temperature extremes. At high temperatures (over 150° F), the grain becomes plastic, and at low temperatures (below −40° F), the grain tends to become brittle. Either of these conditions may cause erratic burning and/or an explosion.

Until recently, the biggest disadvantage of the solid-propellant rocket was its inability to be cooled effectively. However, progress has been made in the design of the solid-propellant grain which allows a considerable degree of cooling. Such a grain has the propellant next to the chamber wall, and the burning takes place on the interior surfaces. This is called an internal burning grain. The thickness of propellant between the flame and the combustion chamber wall acts as an insulating material, and the full heat of the flame is not felt until about the time the grain burns out. Graphite inserts have been used successfully in nozzle cooling.

The recent developments have allowed rocket designers to increase the weight of propellants in missiles since there could be a corresponding decrease in the combustion chamber weight. The development of solid propellants which burn at a lower chamber pressure also allows further decrease in chamber weight and increase in the amount of propellant carried by a solid rocket. These advances give a greater range to a given weight rocket; furthermore, they point the way to the possible development of long-range solid rockets.

To overcome the weight and cooling problems for long-duration units, liquid-propellant rockets are used. Some

problems are helped by the fact that the combustion chamber may be made lighter and smaller. Let us examine the principles of a liquid-fuel motor in figures 5–4 and 5–5. An important point is that the fuel enters the rear of the motor, flows between the walls, cooling the inner surface, and making possible the use of thin-walled combustion chambers. The fuel enters the forward end of the combustion chamber. This is known as regenerative cooling, and the motor is of the regenerative type. The fact that the motor is cooled permits long-duration burning. Because the operating pressure in the combustion chamber is only 250 to 500 lb/in^2, light-weight, liquid-fuel motors may be constructed.

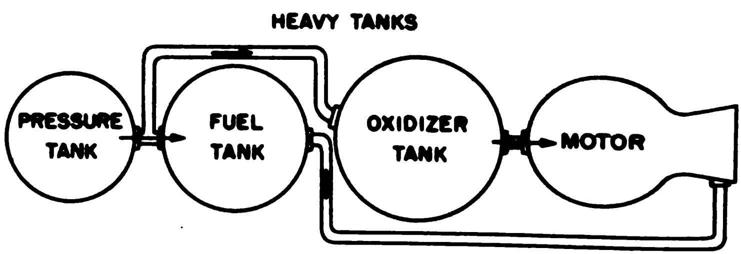


Figure 5–4.—Liquid rocket pressure feed system.

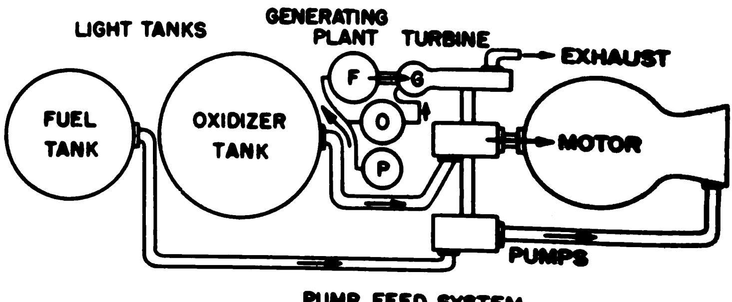


Figure 5–5.—Liquid rocket pump feed system.

Let us now examine the methods of supplying a fuel and an oxidizer from tanks to the motor. There are two methods of doing this which give two main classes of liquid-propellant rockets: the pressure feed system and the pump feed system. The pressure feed system is the less complicated of the two systems, and is shown in figure 5–4. Notice that pressure is supplied to both the fuel and oxidizer tanks. The pressurized air (or inert gas such as helium) is fed through a reduction valve to these two tanks at a pressure of about 500 psia (pounds per square inch absolute), provided the chamber pressure is approximately 300 psia. (Absolute pressure is pressure measured with respect to zero pressure. Gauge pressure is that measured with respect to that of the atmosphere.) As a rule of thumb, the pressure on the propellant tanks must be 200 psi greater than the operating pressure in the combustion chamber. To supply this pressure for the duration of the burning, which may be as long as 50–56 sec, the pressure tank is originally charged to about 150 atmospheres (about 2200 psig) (pounds per square inch gauge). With a pressure of 500 psia or greater on the propellant tanks and 2000 psig in the "air bottle," you can readily see the need for heavy construction. As the size of the rocket increases, the impulse-weight ratio decreases until finally the empty weight of a pressure feed rocket is prohibitive. This limit is about 5 tons. Above this weight a pump feed system is used. However, the pressure feed system is the most economical for light rockets and gives a better impulse-weight ratio.

The pump feed system is essentially the same as the pressure feed system except that the pressure tank is replaced by pumps to force the propellants into the combustion chamber. See figure 5–5. The pumps, of course, must have a power source; so a steam generating plant may be provided to operate a turbine, which in turn drives the pumps. This system has the advantage of having light weight tanks but is, of course, more complicated than the pressure system. It is used on rockets weighing more than

five tons, the V–2 for example. The V–2 uses hydrogen peroxide, which is a monopropellant, and sodium permanganate, a catalyst. Monopropellants are those which contain within themselves both the fuel and oxidizer and are capable of combustion as they exist. Referring to figure 5–5, the hydrogen peroxide would be stored in the tank labeled "O" and sodium permanganate in tank labeled "F". These two constituents, upon combination in the reaction chamber, "G", generate steam. The steam is then used to drive the turbine, which in turn drives the two pumps. Pressure is felt only on the down stream lines; consequently, the fuel and oxidizer tanks can be of much lighter construction.

Other systems supply both fuel and oxidizer for the generating plant, in which case a combustion process takes place in the chamber labeled "G." The small tank, "P," (fig. 5–5) is pressurized air which causes the propellant constituents to flow from "F" and "O" to "G". This small set-up operates as the PRESSURE-FED liquid rocket. The system is far more complicated than the pressure-feed system, but there is a great weight saving since there are no large air bottles and heavy fuel and oxidizer tanks necessary.

Another means of driving the pumps is to place a small turbine in the exhaust jet. This turbine will drive the pumps which in turn put the necessary pressure on the fuel and oxidizer lines. There are also several other means of driving the fuel and oxidizer pumps, but these are the most common ones.

ATMOSPHERIC JETS

It was seen in the foregoing section on rockets that two of the undesirable characteristics of rockets are short burning time and high rate of propellant consumption. The other three jet engines, pulse-jet, ram-jet, and turbo-jet use atmospheric oxygen and carry fuel only. They are, therefore, better in these characteristics. Figure 5–6 shows the cross section of a typical pulse jet. It consists of a tubular

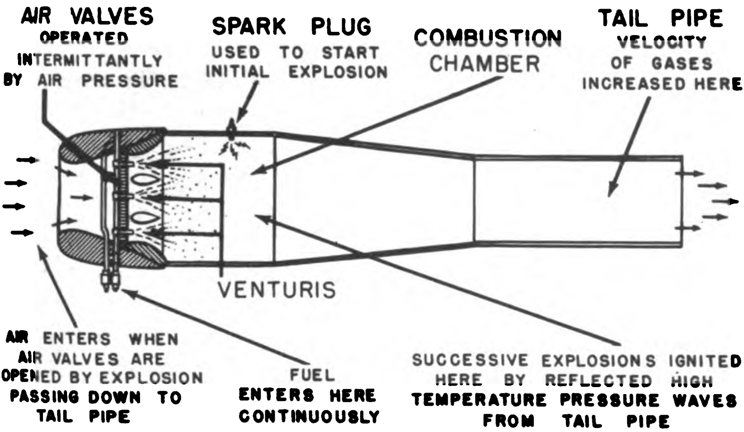


Figure 5–6.—Cross section of pulse-jet engine.

section, with a set of spring-loaded valves and a means provided for injecting fuel, followed by the combustion chamber and the tail pipe.

The operating cycle is as follows. Assume that fuel has been sprayed into the combustion chamber and is ignited by means of a spark plug. Ignition will result, and the gases formed create a pressure of 25 to 35 pounds per square inch. The spring-loaded valves prevent these gases from escaping forward, so they rush out the tail pipe at a high velocity. In fact, they are going so fast that they cause a partial vacuum inside the combustion chamber. This causes the valves to open and permits air to enter the front. Part of the exhaust gases flow back up the tail pipe and meet the air coming in through the open valves. This compresses the new air slightly, and this compression, plus the residual burning fuel, ignites a new charge of fuel which enters at this time. The pressure thus created closes the valves again and the expanding gases rush out the tail pipe. Thus, the action is intermittent, giving rise to the name "intermittent jet" often applied to the pulse jet. It was this intermittent action that gave the V–1 the name "buzz bomb" during the war, for the V–1 was propelled by this type of engine.

The operation described above applies to a stationary pulse jet; however, the same cyclic operation will take place when the engine is in motion. In this case, though, the thrust is increased about 40 percent since the ramming action of the air entering the front aids in increasing the supply of air and the compression. For the V–1 intake, compression, ignition, and exhaust occur at about 40 cps. Operating in the static position, the German V–1 would develop about 500 pounds of thrust. When traveling at a velocity of 340 mph, this same engine would produce 780 pounds of thrust.

The operating frequency in cycles per second in the pulse jet is equal to the velocity of sound propagation divided by four times the length of the tail pipe. ($f = \frac{a}{4L}$). It may seem that more thrust could be developed by the V–1 motor if part of the tail pipe were cut off thus increasing the frequency of cyclic operation. By doing this, however, the weight of air moved per cycle is decreased; hence there is a decrease in thrust. If the tail pipe were lengthened, there would be a decrease in frequency; therefore, it is seen that there is some optimum length for a given engine diameter which will produce a maximum thrust. Under most efficient flying conditions, the V–1 uses about one pound of fuel for each fifteen pounds of air while operating at 40 cycles per second at sea level.

The maximum thrust for a given engine is a function of the frontal area of the combustion chamber. The ratio is about 1⅓ pounds of static thrust per square inch of cross-section area for the V–1. Other pulse-jet engines develop about the same thrust per unit area. Once the area is fixed, then there is some optimum length tail pipe which will allow this maximum thrust to be developed.

The most vulnerable part of this engine is the bank of valves. Because of the short life of these valves, the Germans could obtain only about 30 minutes of operation. One of the improvements that has been made in this country has increased the life of the valves to about 7 hours. This

allows ample time for test runs of the motor; therefore, a complete check-out of the system may be accomplished prior to launching.

RAM-JET ENGINE

The ram jet is an atmospheric thermal jet which does not use a compressor. It is essentially a pipe open at both ends. See figure 5–7. From this the term flying stovepipe originated.

Jet engines are classified according to designed speed, either subsonic or supersonic. The operating cycle is essentially the same for both classes; but other fundamental differences are associated with subsonic and supersonic phenomena. The principal component parts of this engine are (1) the diffuser, (2) the combustion chamber and associated fuel-feed system, and (3) the tail pipe and nozzle. The ram jet differs from the pulse jet in that it can produce no static thrust since it has no value bank to restrict the flow of the working fluid to one direction only. The combustion process in the ram jet is continuous as opposed to the intermittent process of the pulse jet. Since the ram jet cannot

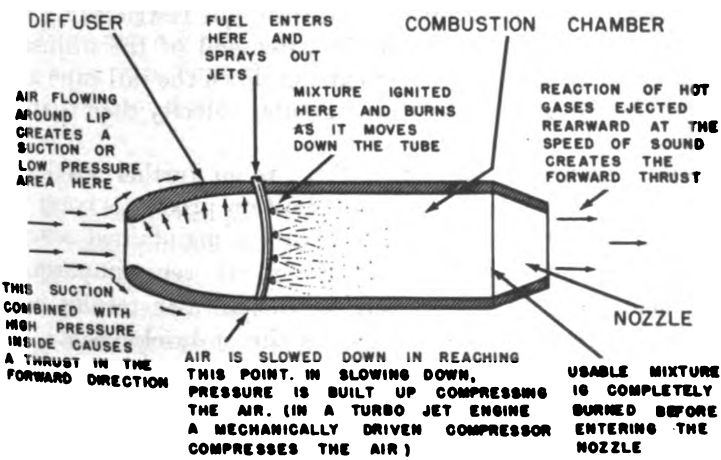


Figure 5–7.—Ram-jet engine.

produce a static thrust, it must be BOOSTED to a speed very near its operating speed before it takes over on its own. In order to attain this speed a rocket or other type of booster is used and it is generally larger and heavier than the ram jet. This engine is ideally suited to long-range high-speed missiles since the thrust increases and the pounds of fuel consumed per second per pound of thrust decreases with speed.

The cycle of subsonic ram-jet operation is as follows:

1. The ram jet is boosted by suitable means to a subsonic velocity. Air enters the diffuser inlet and, due to the diffuser design, decreases in velocity as it approaches the after end of the diffuser.

2. This decrease in velocity is accompanied by an increase in pressure with the result that a relatively high pressure barrier exists at the after end of the diffuser.

3. Fuel, usually kerosene, is sprayed into the combustion chamber through injection nozzles by utilizing a suitable pressure from a pump feed system.

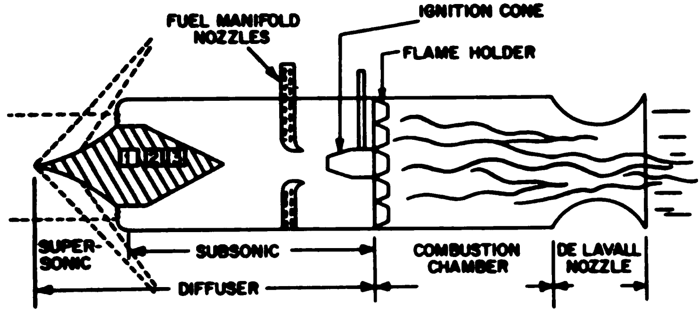
4. This fuel, thoroughly mixed with the incoming air, is ignited by means of a spark plug.

5. The gases of combustion tend to expand in all directions.

6. Expansion in the forward direction is restricted by the pressure barrier existing at the after end of the diffuser; consequently, the gases must expand down the tail pipe and leave the exhaust nozzle with a greater velocity than that of the air at the intake.

Once ignition takes place, there is no further need for an electric spark because the combustion process is continuous as long as the air-fuel mixture is maintained within proper limits. The diffuser design is very important. Efficient recovery of pressure in the diffuser results in a higher pressure barrier and greater thrust development.

The operation of a supersonic ram jet is the same as the subsonic ram jet with the following exceptions. First, the engine must be boosted to a supersonic speed. This results in a normal shock wave being formed on the inlet to the



--- CONICAL SHOCK
NORMAL SHOCK

1. FUEL METERING CONTROL
2. FUEL PUMP OR PRESSURE TANK
3. AIR TURBINE

Figure 5–8.—Supersonic ram jet.

diffuser. See figure 5–8. This shock wave does not interfere with air flow into the diffuser; however, there is a definite pressure rise across the normal shock wave. The second exception is the fact that a higher pressure barrier exists in the supersonic engine causing a resulting increase in thrust.

Differences in the physical design of the ram jet exist but these will not be discussed in this text. It is sufficient to show the basic design. In summary, the engine is simple with no moving parts; it is light in weight; it is easy to manufacture; it is limited to operation in the atmosphere and it uses common fuels.

TURBO JETS

TURBO JETS are particularly suited for use in aircraft and long-range missiles because their specific fuel consumption approaches that of the conventional aircraft engine. In addition, the turbo jet is an atmospheric jet engine capable of delivering sufficient STATIC THRUST—thrust developed with the vehicle not in motion—to enable an aircraft or missile to take off under its own power.

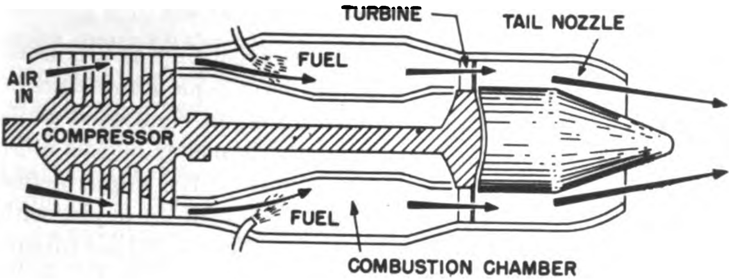
The axial-flow turbo jet and the centrifugal-flow turbo jet have the same operating cycle; the only difference between

the two is the manner in which air compression takes place. Figure 5–9A is a schematic illustration of the axial-flow turbo jet. A starting motor causes the compressor and the turbine to rotate at a desired speed. The compressor draws in a charge of air, compresses it, and forces it into the combustion chamber where it is mixed with the fuel and ignited by means of an electric spark. The hot gases of combustion and the excess air are then directed against the blades, or buckets, of a gas turbine, causing it to rotate at high speed. The turbine is connected directly to the compressor by a shaft, and as soon as the turbine takes over, the starting motor is disconnected. Only a part of the heat energy released by the combustion process is used to drive the turbine; the remainder is available for conversion into kinetic energy by expansion through the nozzle. The turbine develops sufficient power to operate auxiliaries such as fuel pumps and generators in addition to driving the compressor.

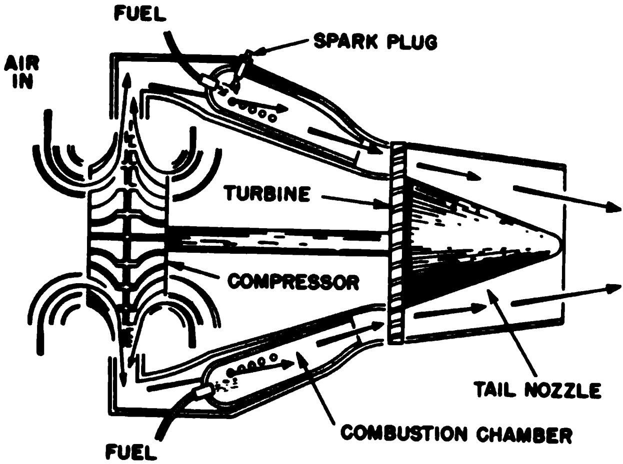
Note, in figure 5–9B, the various compressor stages and the decrease in air-passage area from the inlet to the outlet of the compressor. The axial-flow turbo jet is longer than the centrifugal-flow type, but has a smaller frontal area, and consequently lends itself to a low-drag aerodynamic configuration.

The thrust of a turbo jet decreases with increasing altitude, but it is nearly constant over a speed range of from 0 to 650 mph for a given altitude. There is a slight increase in thrust as speeds in excess of about 300 mph are obtained because of the beneficial effects of ram air compression—that is, compression of the inlet air due to the relative motion between the air and the compressor inlet. The specific fuel consumption of a turbo jet decreases with increases in altitude. This fact, plus the fact that the thrust increases slightly at high speeds, places the optimum operating point of the turbo jet in the high-speed, high-altitude region.

Combination.—Each type of jet power plant has definite operating characteristics which in general differ rather widely from one another. Because of the widely different



(A) SCHEMATIC AXIAL-FLOW TURBOJET



(B) SCHEMATIC CENTRIFUGAL-FLOW TURBOJET

Figure 5–9.—Turbo jets.

requirements dependent upon launching systems, designed range and other parameters, each type of jet engine has definite applications. Because of these characteristics it may be necessary to employ two different types of power plants for one missile. The *Regulus*, for instance, employs a turbojet power plant but requires a rocket booster to launch it under certain applications. The *Talos* is another missile type which employs a combination of engines, a rocket to BOOST it to speed and a ram-jet sustaining engine.

Launchers are not within your responsibility as a Guided Missileman. However, you should have some knowledge of what they are. Some of your work may be conducted while the missile is on the launcher and the launcher details must be known to you. What is a launcher? We might define it as an apparatus which sends or shoves off an object with force. This definition is not complete for the guided missile launcher, however. Strictly speaking, a guided missile launcher is a mechanical structure that ORIENTS a missile prior to firing and, in specific instances, CONTROLS the missile during initial motion by making it move in the desired direction of flight. Thus a guided missile launcher does more than just force a missile into the air. Orientation and control are the factors which distinguish it as a guided missile launcher.

The purpose of the launchers are determined by technical and tactical requirements. A launcher which meets only the technical requirements could be permanently placed, simple in construction, and satisfactory for test purposes but of no use as a tactical mechanism. Tactical launching devices must be trainable, transportable and capable of rapid loading. Such a launcher must be constructed for a specific missile and consideration must be given to the method of propulsion, guidance and aerodynamics. The technical requirements of (1) acceleration and (2) guidance and stability are the basic requirements of any launching system.

There is a definite limit to the acceleration forces that the missile airframe and components can withstand. The acceleration limit is a distinct disadvantage to some types of launching. A very high thrust, high-acceleration missile requires a shorter launcher than a low-thrust, low-acceleration missile of comparable operating speed.

The guiding and launching of a missile are very closely related. The launching system must provide the missile with original guidance for the initial part of its flight to the point where the guidance system can take over control. This guidance is generally effected by orienting the missile and

starting it in stable flight and in the required direction. Because many of the supersonic missiles designs are not aerodynamically stable at subsonic velocities, the booster unit must be equipped with sufficient aerodynamic surfaces to give the missile initial stability until it attains its operating velocity. A BOOSTER is a unit which travels with the missile and supplies the thrust during the acceleration period, after which it is automatically separated from the missile. The booster units are one of the most important parts in some types of launching.

The intended tactical uses of missiles influence the launcher characteristics. A surface-to-air missile launcher must be capable of being loaded rapidly and must be trainable. A surface-to-surface missile launcher is in general heavier and the ability to train it is less critical.

Launchers for guided missiles may be separated into two classifications: FIXED LAUNCHERS, which send the missile off in a given direction not necessarily pointed at the target, and TRAINABLE LAUNCHERS, which dispatch the missile in the direction of the target.

Within the two classifications many types of launchers may be found. The first of these is the TRAINABLE PLATFORM. It consists of a horizontal platform upon which the missile is placed for vertical launching. A training ring enables the missile to be oriented in azimuth and provision is made for a leveling device.

In order to explain orientation in azimuth of a missile in a vertical position we will make reference to the V–2 missile. In that missile it was necessary to point the number one jet vane in the direction of the target before firing since that vane and its counterpart controlled the direction of flight and roll stabilization. In effect the missile reference represented by the jet vane was trained in azimuth. See figure 5–10. In vertical launching a ballistic-type missile needs to develop only enough thrust to overcome the force of gravity. This type missile is controlled by other than aerodynamic means because the control surfaces have

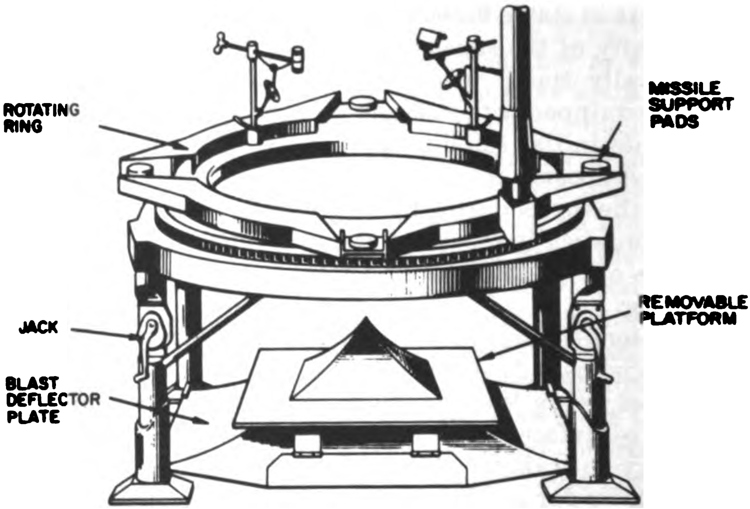


Figure 5–10.—Vertical tower launcher.

little effect during this slow speed phase. Jet vanes, movable jets, or some other type of initial control must be used.

The vertical tower launcher is a mechanical device of derrick-type construction which orients the missile in a vertical (or near vertical) direction before firing and which constrains the missile to travel in that direction for the length of the launcher. This launcher has been adopted for high altitude rocket launching because of missile simplicity made possible by such launching. The tower is made high enough so that arrowlike stability has been attained by the missile on leaving the launcher. Control instruments, therefore, need not be used and the weight and space thus made available can be converted into additional altitude or additional research instruments. An example of a vertical tower launcher is shown in figure 5–11. It is the launcher used with the *WAC Corporal* missile.

A vertical rail launcher accomplishes the same purpose as the vertical tower except that a rail or rails take the place of the derrick-type structure and are normally short in

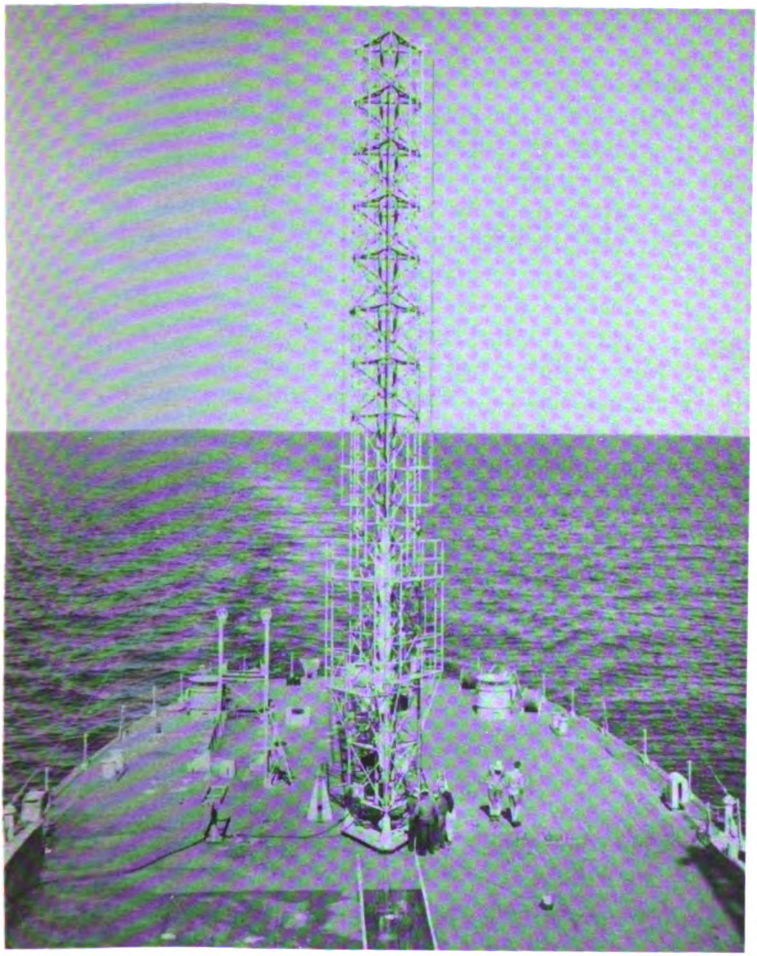


Figure 5–11.—Vertical tower launcher.

length. This launcher is well suited to the launching of radio or radar command guidance surface-to-air missiles, since a vertically launched missile need not be launched toward the target but can be guided in azimuth to any point on the compass after launching. However, the use of a

booster makes launching especially hazardous for this missile.

ZERO LENGTH LAUNCHER is a rail-type launcher of such short length as to have no appreciable constraining action on the missile after firing. High-thrust boosters must be used in launching because flying speed must be attained in a very small fraction of a second. A shear pin or strut is usually used in the launcher to allow thrust to build up to a point where successful launching is assured. Zero length launchers are designed expressly for surface-to-air missiles where high-thrust boosters would be used, and where rapid loading can be made easier by the simplicity of the mechanisms for attaching the missile to the launcher. This launcher may or may not be of the trainable classification. Those used with the *Terrier* missile are of the trainable type.

The RAMP OR RAIL LAUNCHER orients and constrains the missile in direction and elevation (not vertical). It may be fixed or capable of being trained and elevated. The traversable or trainable ramp or rail, especially if of short length, is suitable for tactical use. The *Regulus* missile uses this type of launcher which is shown in figure 2–11.

A catapult is a device which converts electrical or pressure energy into mechanical motion of the car or sled to which the missile is attached. The catapult provides constraining action for its length and, in addition, accelerates the missile to operating speed. Thus, the catapult is a special type of launching device since a thrust is transmitted by it to the missile. The method by which a catapult converts electrical or pressure energy into motion is a much more efficient method than that employed by boosters. However, the catapult is a large expensive piece of equipment so that its efficiency of operation will provide overall economy only after repeated launchings.

The catapult type of guided missile launcher finds its greatest usefulness on shipboard where mobility of the catapult is not of great importance since the platform on which

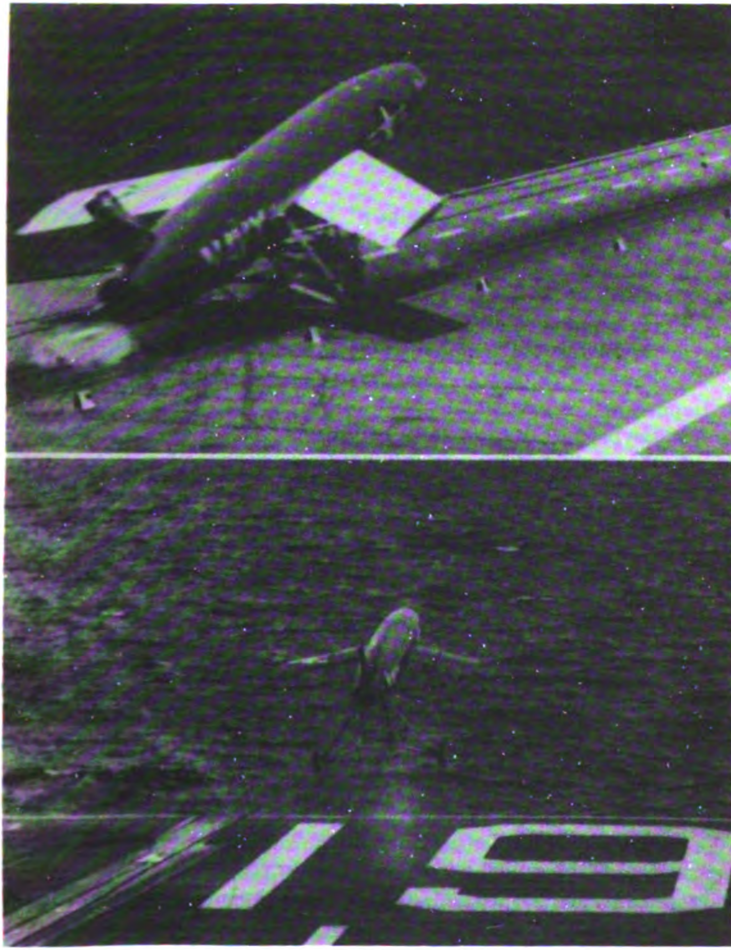


Figure 5–12.—*Regulus* catapult launch.

it is installed is highly mobile. The catapult is used with the *Regulus* missile when it is employed on CVA type aircraft carriers. See figure 5–12. When land based, the catapult will probably be used in static situations because its bulk and weight normally prohibit its being made mobile or transportable.

QUIZ

1. The type of propulsion most likely to be found in a guided missile would be a
   a. mechanical jet
   b. thermal jet
   c. terra jet
   d. hydro jet
2. A jet engine obtains its thrust by
   a. increasing the momentum of the exhaust gases
   b. pushing the jet exhaust against the surrounding atmosphere
   c. the vacuum created in its wake
   d. increasing the momentum of the medium immediately adjacent to its path
3. Impulse is
   a. the product of force times distance
   b. the product of velocity times distance
   c. the product of mass times acceleration
   d. the application of a force for a given period of time
4. All jet engines have which of the following components?
   a. Combustion chamber, fuel supply system, nozzle or exhaust pipe
   b. Mechanical compressor, combustion chamber, and nozzle or exhaust pipe
   c. Thermal compressor, combustion chamber, and fuel system
   d. Compressor, combustion chamber, and nozzle or exhaust pipe
5. Which of the following is an advantage of a restricted burning solid rocket over an unrestricted burning solid rocket?
   a. Gives higher thrust per given period of time
   b. Produces thrust for longer period of time
   c. Provides faster energy utilization
   d. It is better suited for use as a booster rocket
6. Liquid rockets can use thin-walled combustion chambers because
   a. the fuel is used to cool the walls
   b. the walls are cooled by exposure to the atmosphere
   c. the combustion process in a liquid rocket produces less heat than in a solid rocket
   d. they are surrounded by a non-combustible coolant
7. The two types of liquid rockets are
   a. restricted and unrestricted burning
   b. restricted and pump feed
   c. unrestricted and pump feed
   d. pressure feed and pump feed

8. Which class of liquid rocket is used for extremely large missiles in order to limit the weight to impulse ratio?

9. Which of the following jet engines carries its own oxidizer?
   a. Turbo
   b. Rocket
   c. Pulse
   d. Ram

10. The thrust of a pulse jet in motion is about -------- percent greater than a stationary pulse jet.
    a. 20
    b. 40
    c. 60
    d. 80

11. The part of a pulse jet most vulnerable to wear is the
    a. intake nozzle
    b. combuster chamber wall
    c. bank of valves
    d. tail pipe

12. Ram-jet engines are classified primarily according to their
    a. weight
    b. fuel
    c. length
    d. speed

13. Which of the following is a correct statement?
    a. Supersonic ram jets are most efficient at Mach 0.8.
    b. Ram jets can develop no static thrust.
    c. Rocket motors are incapable of flight within the earth's atmosphere.
    d. Ram jets are the most efficient jet power source outside the earth's atmosphere.

14. The component of a ram jet which changes a high speed, low pressure flow of gas into a low speed, high pressure flow is known as the
    a. diffuser
    b. combuster
    c. igniter
    d. nozzle

15. Boosters are added to guided missiles
    a. for use in case the main power plant fails
    b. to force the fuel into the combustion chamber
    c. to attain effective initial operating speed
    d. to eliminate the need for launching ramp or platform

16. The best operating condition for a turbo jet is in a high-speed, high-altitude region because
    a. optimum fuel consumption and thrust are obtained
    b. optimum fuel consumption and an absence of ram air compression obtained
    c. there is an absence of ram air compression and longer valve life is obtained

17. The basic requirements for any launcher system are to
    a. orient the missile and to impart initial thrust
    b. orient the missile and control its initial motion
    c. provide initial thrust and control the missile's initial motion
    d. be light in weight and rugged enough to withstand missile acceleration

18. What are the two classifications of launchers for guided missiles?

19. The *Terrier* missile is launched from a
    a. trainable platform launcher
    b. rail launcher
    c. ramp launcher
    d. zero length launcher

20. A catapult type launcher eliminates the need for
    a. stabilization fins
    b. a missile booster
    c. missile orientation
    d. initial control of missile flight

CHAPTER 6

AUXILIARY POWER SUPPLIES

The auxiliary power supply is by definition a power source providing electrical or some other form of energy for guidance and control of a guided missile. Power supplies can be of the dynamic type, using rotary electrical machinery and hydraulic pumping units, or of the static type in which electric or hydraulic energy is stored in and liberated from batteries and accumulators respectively. This definition is to differentiate between the auxiliary power supply and the power supply used to drive the missile through the air.

An auxiliary power supply for missile application should possess the following characteristics: (1) a long shelf life for a wide range of storage conditions, (2) the ability to supply power immediately upon demand, (3) be of minimum weight and size, and (4) the ability to deliver output power, within specification limits, under the environmental conditions of launching and flight.

What methods are used to generate the auxiliary power required? Before this question can be answered certain things must be known, such as, what components are to be supplied; how much power do they need; how much space is available to house the generating equipment? These problems belong to the design engineer and are not the consideration of this chapter. It can be said, however, that the guided missile field is in a state of constant change and many types

of auxiliary power supplies are in use, and no two missiles use exactly the same types. Here we shall describe some of those power supplies which are now in use or may be used in the near future.

THE PNEUMATIC SYSTEM

The first system which we shall cover is a pneumatic system shown diagrammatically in figure 6–1. It uses the potential energy of compressed air stored in an air flask at about 3,000 pounds per square inch (psi). The flask is charged through a fill valve. An air filter removes any relatively large impurities which may have been in the charging air. On the output side of the flask is another filter of finer mesh than that on the input to the flask. The purpose of this filter is to remove any particles which may have been deposited in the flask. The initiating valve is of the piston type and is held in the closed position by a pin. This valve is opened rapidly by the flask air pressure acting on the differential area of the piston thus satisfying the characteristic of sup-

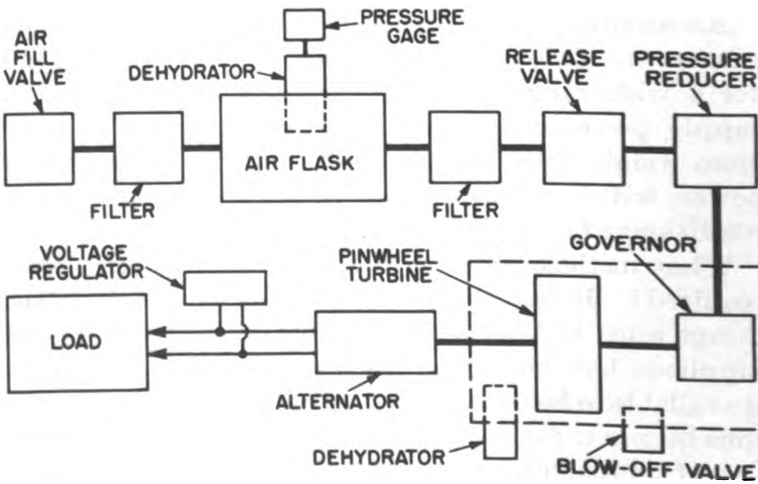


Figure 6–1.—Pneumatic system.

plying power immediately upon demand. The release pin may be removed by hand or, with some modification, electrically. The spring located to the left of the differential piston, as shown in figure 6–2, takes up the shock caused by the rapid opening of the valve. The O-rings are seals, doughnut shaped, and are used for effective sealing in both directions. The sealing characteristics of O-ring seals is their ability to spread against the groove in which they are installed when pressure is applied on one side or the other of the working part.

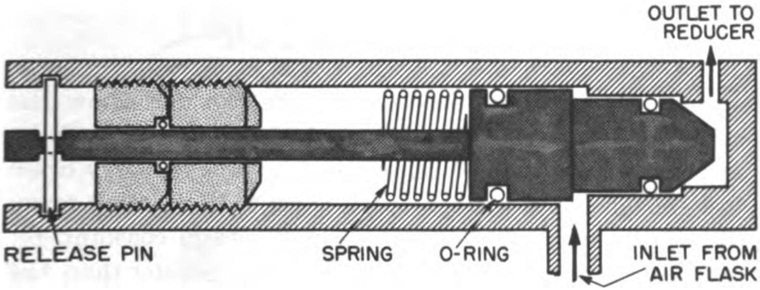


Figure 6–2.—Initiating valve.

The high pressure air of the flask is fed to a reducer valve where the pressure is dropped from 3,000 psi to approximately 300 psi for use in the turbine. Figure 6–3 shows a simple pressure reducing valve. This type may be described as one in which the output pressure tends to close the valve which is held open by a spring. The valve of the output pressure may or may not be variable. The valve operates in the following manner. Suppose the spring is set for an output pressure of 300 psi and the input is 3,000 psi. As the pressure in chamber "A" builds up from 0 or some value less than 300 psi to some value greater than 300 psi the spring will no longer hold the valve off its seat and the input from chamber "B" will be shut off. As the pressure in chamber "A" decreases, due to use in some equipment, the

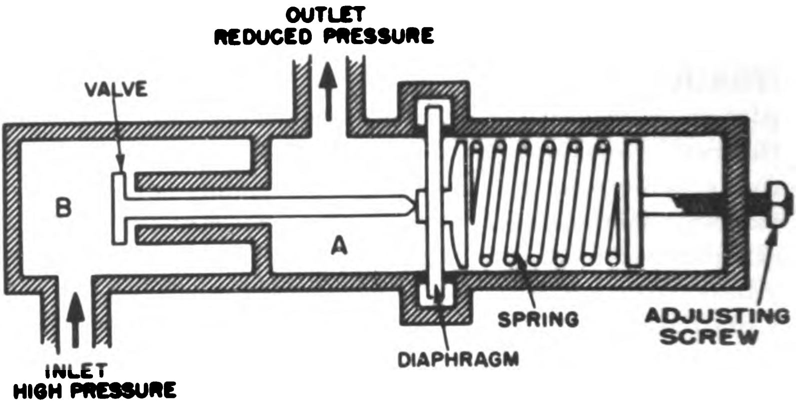


Figure 6–3.—Simple reducing valve.

spring will again lift the valve off the seat and allow the air to flow through it. At some pressure a balance will be reached, in this case 300 psi, where the valve will stay open just enough to allow a constant 300 psi to be expelled from the output. The output pressure will remain constant regardless of the input so long as the input is greater than the desired output.

There are many designs of reducer valves; you will obtain knowledge of these from the particular missile manuals from which you will work. The one just described is a common type.

TURBINES

A turbine operates from a fixed volume air flask and therefore the selection of the operating pressure is a compromise between the quantity of air which can be released from the flask and the energy which may be derived from that air. At high operating pressures more energy can be obtained from the air but less air can be removed from the tank. This is obvious since as air is removed the pressure is reduced until the point is reached where the pressure supplied is below the operating pressure. The optimum

operating pressure for this particular system is approximately 300 psi.

A pinwheel type reaction turbine is used in the auxiliary power supply described here. The performance of this type turbine is a function of the operating pressure, the speed, the arm length, the shape of the arm, and the nozzle size. Figure 6–4 illustrates a form of this pinwheel.

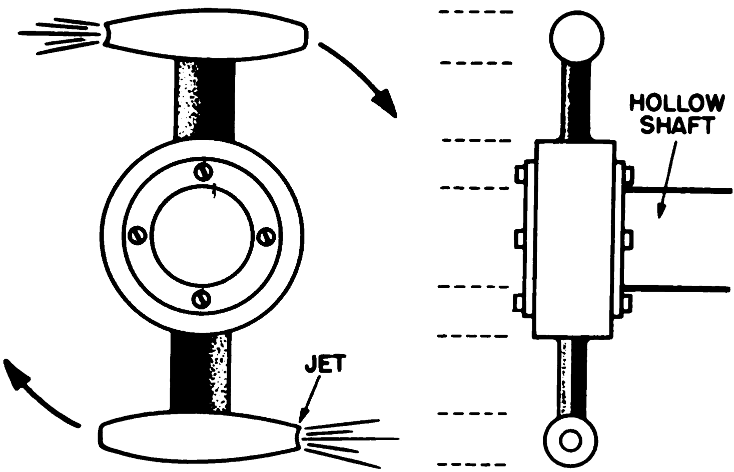
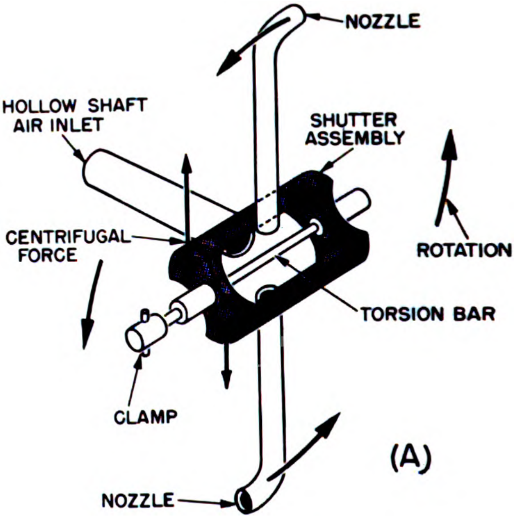


Figure 6–4.—Pinwheel turbine.

The pinwheel has two jet vanes diametrically opposite each other and mounted on a hub. The air is led into the pinwheel through the hollow shaft upon which it is mounted. Within the hub of the pinwheel is located the governor for the turbine. This governor consists of an unbalanced drum type shutter whose axis lies in the plane of pinwheel rotation.

Centrifugal force working on the unbalanced shutter causes the drum to rotate about its own axis thereby closing the ports to the pinwheel nozzles; see figure 6–5B. The torque developed by the drum due to the centrifugal force



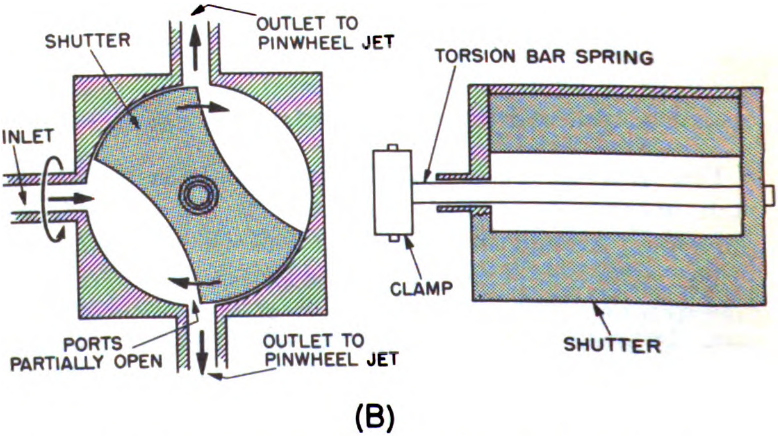


Figure 6–5.—(A) Pinwheel governor; (B) Governor shutter arrangement.

is opposed by a torsion bar spring; see figure 6–5A. Because of the tension set up by the spring, the drum will seek a definite position for any particular speed of the pinwheel. The governor has been designed so that the torque of the spring approaches the centrifugal torque at a high rate as the drum moves to a position of equilibrium.

The alternator, driven by the pinwheel turbine, is a self excited rotating armature type unit supplying 400-cycle power at approximately 24,000 rpm. The principles of operation of this type alternator are explained in chapter 14 of *Basic Electricity* (NavPers 10086).

The dehydrators used in the system are located in the air flask and in the mounting head. The purpose of these is to remove or reduce the moisture content of the air, thereby preventing condensation at low temperatures and the formation of ice on the various parts of the system.

The principle purpose of the blow-off valve is to seal the unit against dirt and moisture during storage. The valve is designed to open at a low pressure differential so as to prevent excessive back pressure on the turbine when operating at or near sea level conditions. Figure 6–6 pictures a type of blow-off valve.

The auxiliary power supply which we have covered might be used to supply an all-electric control system, as described later in chapter 11 of this text, in addition to the guidance

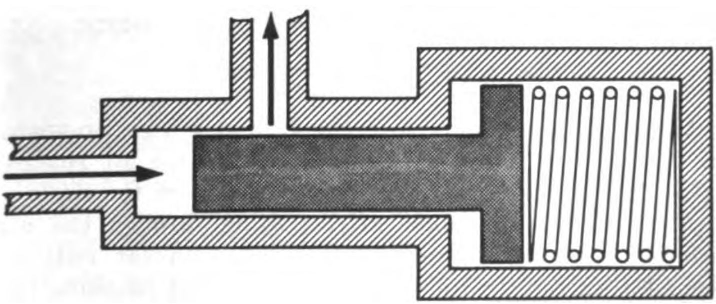


Figure 6–6.—Blow-off valve.

system of a missile. It is conceivable that it might be used to supply power for a hydraulic control system also. In this case the electrical energy would have to be transformed by means of an electric motor connected to a hydraulic pump into hydraulic energy.

PNEUMATIC-HYDRAULIC SYSTEM

The description of a system which supplies both electric and hydraulic energy within the single unit follows. It can be classified as a pneumatic-hydraulic system. Refer to figure 6–7. The components of this system, in the order of use, are: an air flask or accumulator, a pressure regulator, an air motor, a hydraulic motor, an alternator and the necessary transformers and rectifying equipment.

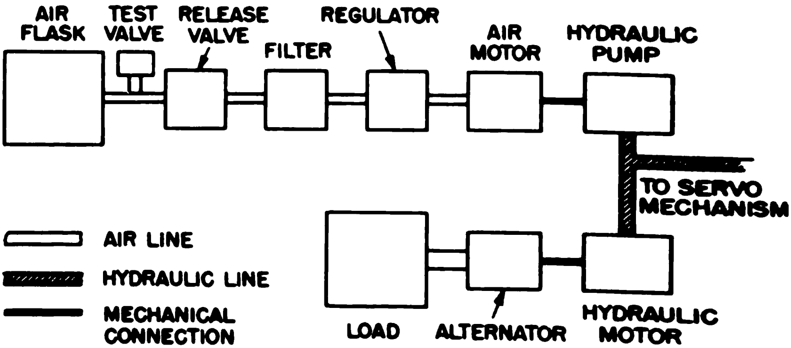


Figure 6–7.—Pneumatic-hydraulic system.

Air or nitrogen is stored in the flask at a high pressure, on the order of 3,000 to 5,000 psi. When the air release valve on the flask opens, the energy stored in the flask is supplied to the air motor after passing through the air reducer-regulator. Figure 6–8 shows a typical reducer-regulator valve. In the absence of any inlet pressure the spring keeps the poppet valve open. When pressure is applied, the high pressure air passes through the poppet sec-

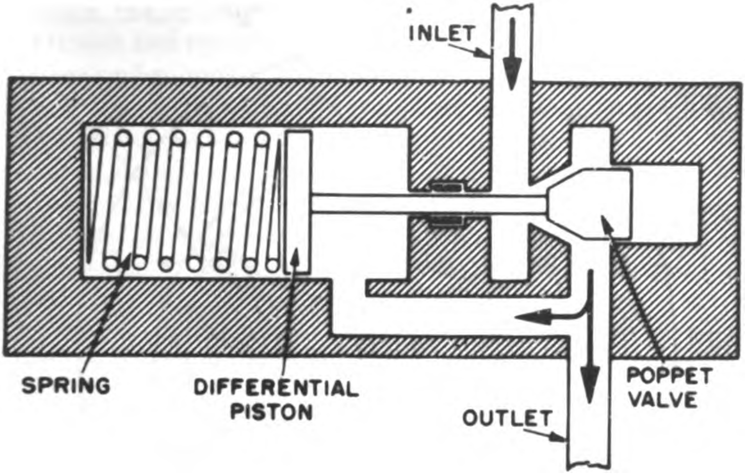


Figure 6–8.—Reducer regulator valve.

tion of the valve and also acts on the differential piston and against the force of the spring.

If the spring tension is set for an output of 200 psi on top of the differential piston and 3,000 psi acts on the underside of the piston, it will cause the poppet valve to close until such time as the outlet pressure reaches the set value. The amount of flow of air through the poppet valve is variable because of the construction of the seat for the poppet valve. The amount of air pressure is regulated by increasing or decreasing the tension of the spring.

Air Motor

The air motor transforms the pneumatic energy to hydraulic energy. The motor is represented by the drawing in figure 6–9. This particular type of air motor works on the principle of differential areas. The air enters the inlet port and its pressure is exerted against the chamber wall, the rotor, and surfaces "1" and "2." Because the area of "1" is greater than the area of "2," the rotor is caused to turn,

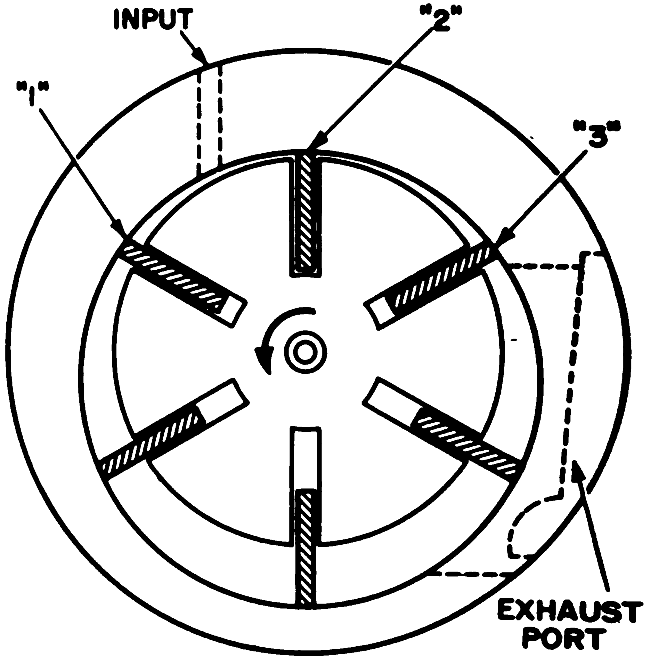


Figure 6–9.—Air motor.

since the pressure is exerted over a greater area thus producing a larger force. As the rotor turns the area of "1" and "2" becomes progressively larger as each of the vanes slides out of the rotor recesses. When vane "3" is in a position to be acted upon by the air pressure, the "1" vane has been isolated from the input port and vanes "2" and "3" assume the differential area situation. The potential energy of the high pressure air has, at this point, become kinetic energy and powers the hydraulic pump. The hydraulic pump supplies two sources of energy. One causes the control surfaces tc move and the other causes a generator to produce electrical energy for the guidance and control systems. Hydraulic pumps take many forms. One type which we shall consider here is the rotating barrel type. This type gives a continuous flow with positive displacement.

Both the hydraulic pump and motor are similar in construction and operating principles. They each have an odd number of cylinders in a cylinder block arranged parallel to the drive shaft, with a piston moving to and fro in each. Each piston rod is linked by a ball and socket joint to a rotating plate called a socket ring. See figure 6–10. The socket ring is linked to the shaft of the driver by a universal joint and bears against a tilt plate whose surface is tilted at a fixed angle with respect to the shaft. When the mechanism acts as a pump, the following action takes place. The shaft rotates causing the piston to move up in the cylinder block forcing hydraulic fluid out of the pump. When it reaches the top of the stroke, the piston starts to move out thereby drawing oil into the pump. Actually both the pump and the motor have an odd number of pistons and if there are nine of them, four are pumping and four are drawing fluid back from the motor. The remaining one faces a blank space on the valve plate. This valve plate contains eight cylinder ports. The reason for the odd number of pistons and even number of ports is to prevent hydraulic shock. If there were

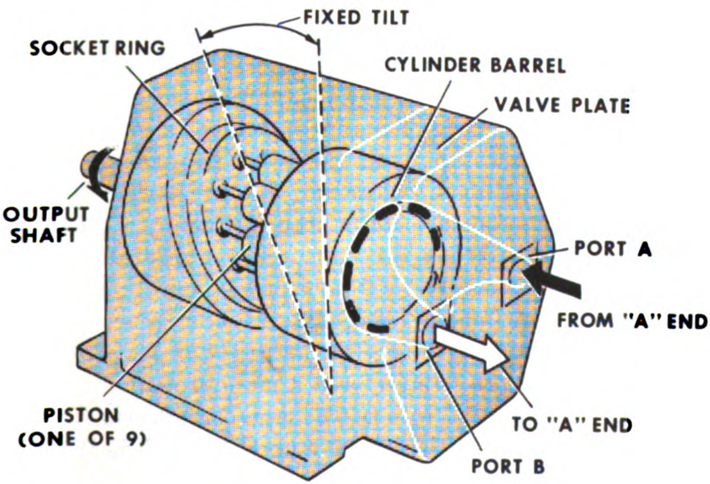


Figure 6–10.—Hydraulic pump.

the same number of ports as there were pistons, two pistons, one at the top and one at the bottom, would be blocked at the same time and the flow into and out of the cylinder would be suddenly interrupted. The motor working in the same manner as the pump has fluid forced into it and drawn from it thereby causing it to rotate and drive the alternator.

The manner in which the hydraulic and pump supplies hydraulic pressure for control surface actuation will be covered under the hydraulic control systems in chapter 12. The alternator will be taken up later in this chapter.

HOT GAS SYSTEMS

Another type of APS is that which employs a hot gas turbine in lieu of one which is driven by compressed air. The gases used are generated by the combustion of either a solid propellant or a liquid propellant. The liquid propellants are classified as MONOPROPELLANTS or as BIPROPELLANTS.

Bipropellants are those in which the fuel and oxidizer are kept physically separated until they are injected into the combustion chamber. Monopropellants have been previously defined. An example of a monopropellant would be the mixture of hydrogen peroxide and ethyl alcohol; an example of a bipropellant would be analine, an oily clear liquid, and red fuming nitric acid. The bipropellants, in general, offer higher performance than do the solid propellants or the liquid monopropellants. However, due to the fact that the turbine inlet temperature is the limiting factor in the choice of a propellant, it is not necessary or even desirable to employ the bipropellant in auxiliary power supply units. A liquid monopropellant is completely reliable when less specific energy is required; hence the majority of gas generators which use liquid propellants used a monopropellant.

Monopropellants fall into two general classifications. The first consists of liquids which give up their high heat of decomposition when initiated thermally. The second consists of liquid solutions of fuels and oxidants, the constituents of

which are compatible in storage and can be made to liberate energy of combination upon thermal initiation.

SOLID PROPELLANT SYSTEM

A solid propellant system is shown in figure 6–11. The package consists of: (1) a combustion chamber containing the solid propellant grain and a gas pressure regulator (2) a cylindrical hydraulic accumulator and a hydraulic regulating valve and (3) a turbine driven alternator and speed regulator. Electronic rectifier and regulator chassis are used to convert the output of the alternator to the necessary d-c voltages. In operation the products of combustion of the propellant are directed into the gas side of the accumulator expelling the fluid at a pressure of approximately 2000 psi to the hydraulic load. The hot gases are also used to drive a multiply re-entry turbine alternator unit. A constant speed and thus electrical frequency is maintained by means of a flyball type of speed governor.

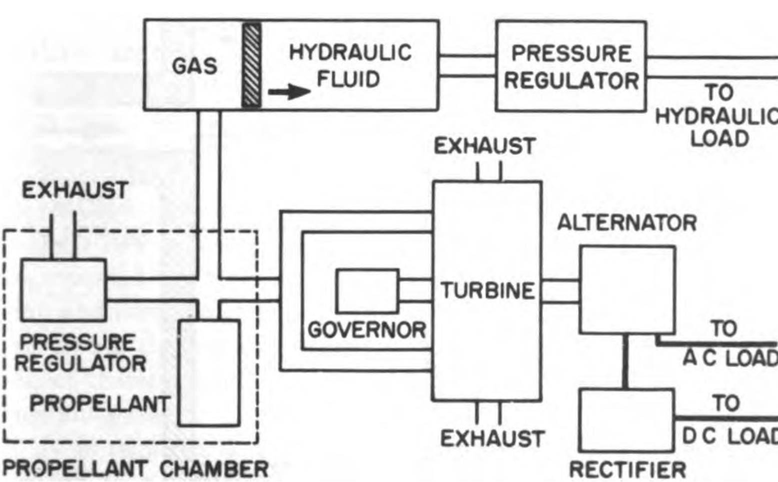


Figure 6–11.—Solid propellant system.

The propellant chamber in this system contains the propellant charge which may be a restricted end-burning grain. The principles of rocket motors described in chapter 5 of this text apply to these propellant grains. The igniter for the propellant grain may consist of black powder. It is required to do two things. The first is to raise the pressure in the combustion chamber to some percentage value of the operating pressure and the second is to raise the temperature of the face of the propellant to a value which

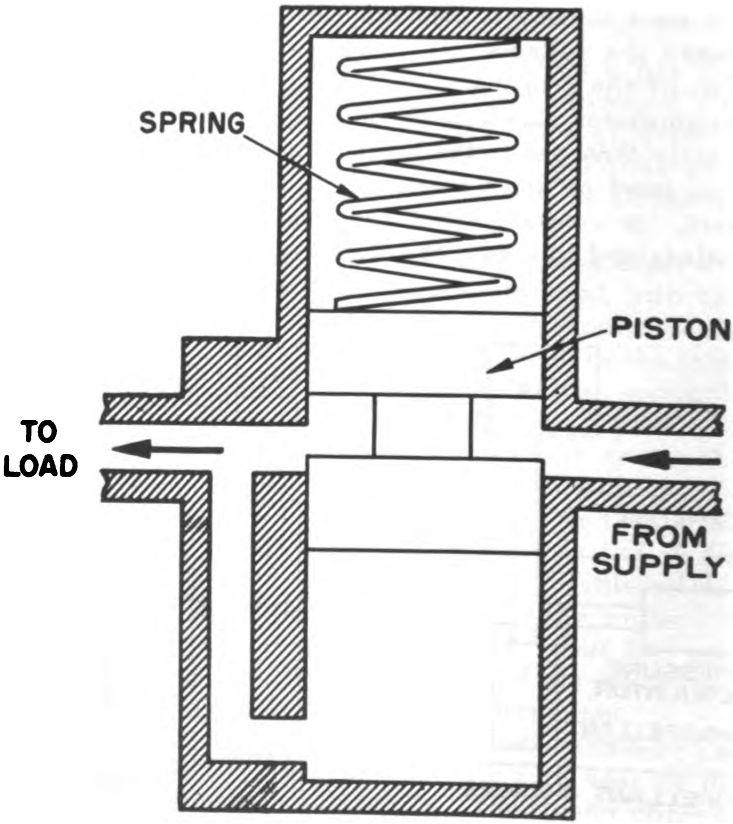


Figure 6–12.—Pressure cut-off valve.

will maintain continuous burning. A SQUIB (refer to appendix 3) is used to initiate the igniter. As the propellant burns it generates a gas which is supplied to the hydraulic accumulator and to the turbine. The regulating valve in the gas system is a safety valve and exhausts to the atmosphere when the pressure exceeds the value set on the spring within the valve. The gas pressure forces the free floating piston of the accumulator in the direction shown, thereby supplying the hydraulic pressure required. The regulating valve is a pressure cut-off valve as shown in figure 6–12. The load pressure acting on the side of the piston is balanced by the spring. A rise in the load pressure causes the piston to move against the spring to throttle the inlet flow from the accumulator. A decrease in load pressure causes the valve to open and increase the flow.

The gases generated by the propellant also drive the hot gas turbine; refer to figure 6–13. The turbine wheel is a solid piece of steel having buckets of semi-circular recesses milled into its periphery. Around this wheel and mounted to the casing are four nozzles spaced 90° apart. Also within the casing are a series of stationary semi-circular reversing chambers. The products of combustion from the solid propellant are distributed through a gas manifold ring and pass through the nozzles where they are expanded to exhaust pressure. The gas impinges at high velocity on the side of the wheel buckets. In passing through these buckets it is reversed 180°. The gases are then caught by a semi-circular reversing chamber in the housing where they are again reversed 180° and returned to the turbine wheel. The process is repeated five times through a 90° arc of the turbine housing and then the gases are passed overboard. The process of reversing the hot gases several times gives a multiple-stage effect thereby using more of the available energy in the propellant gases.

It is required that the frequency of alternators be maintained to a close tolerance. This control can be provided by a speed regulator of the mechanical flyball type governor

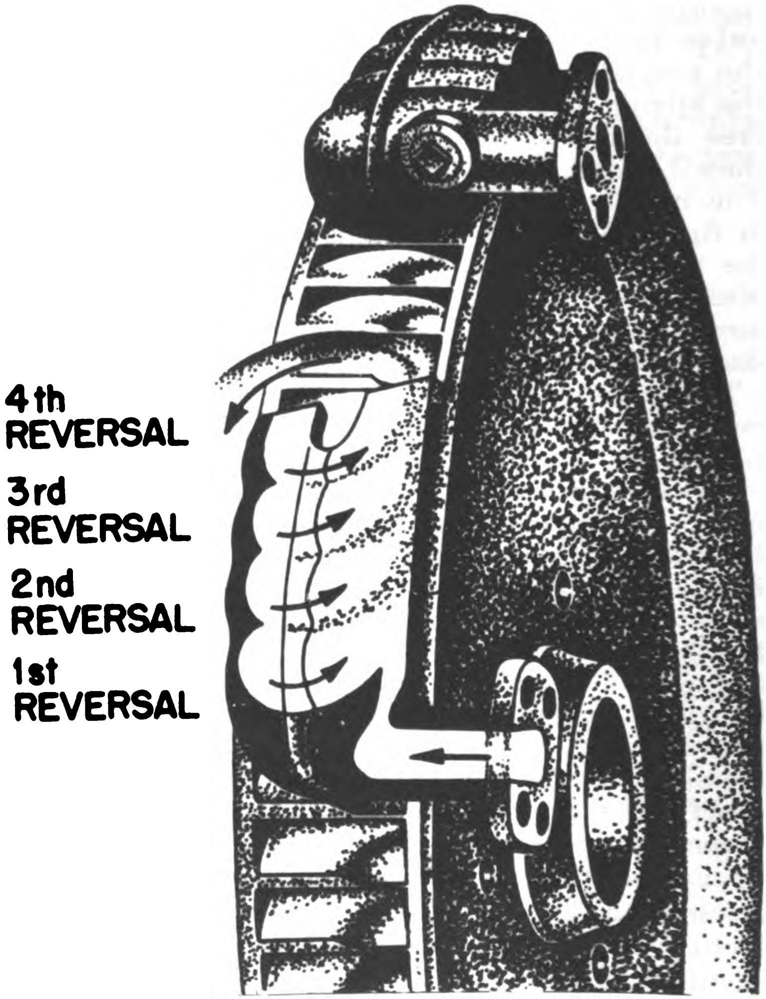


Figure 6–13.—Terry type turbine.

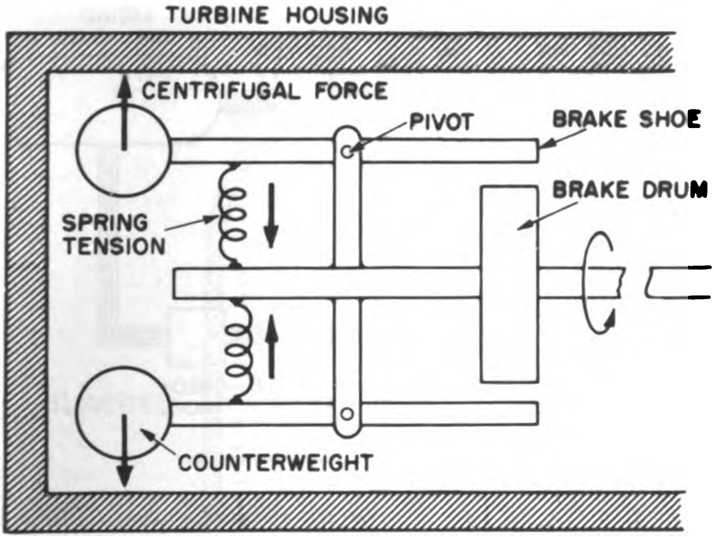


Figure 6–14.—Flyball type governor.

illustrated in figure 6–14. A coiled spring provides a restraining force to a pair of pivoted counterweights mounted on a common shaft. These springs keep the counterweights away from the turbine housing. When the shaft speed approaches a predetermined speed, the centrifugal force is sufficient to overcome the spring tension and allows the counterweights to pivot and contact the braking surface. This braking action slows the alternator. As a result of a decrease in speed of the alternator the centrifugal force acting on the counterweights is reduced resulting in corresponding reduction of the braking action. A constant speed is maintained as a result of the frictional torque produced by the braking surface.

LIQUID PROPELLANT SYSTEM

A basic liquid propellant system is shown in figure 6–15. The action of the system is as follows. The high pressure gas flows from the gas flask through the arming valve, when

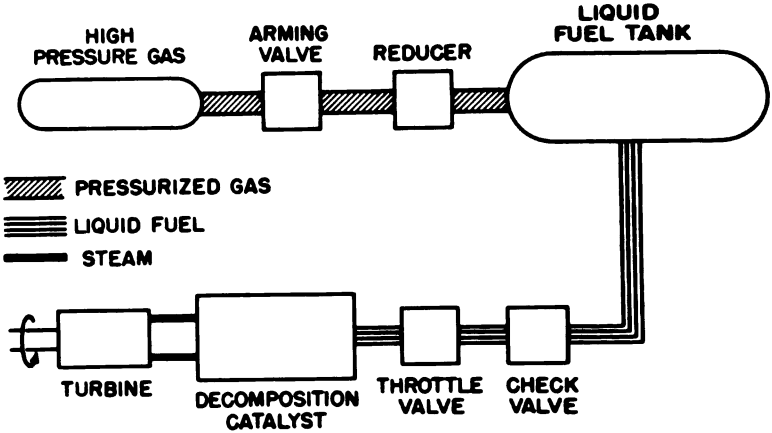


Figure 6–15.—Liquid propellant system.

tripped, and then to the pressure reducer valve. The use of this valve allows storage of gases at a high pressure thus minimizing the size of the container and providing for a relatively easy control problem by maintaining a fuel supply pressure. After leaving the pressure reducer valve, the gas flows into the fuel tank bladder. The fuel tank, figure 6–16, consists of two containers—one inside the other. The fuel proper, in this case hydrogen peroxide, is stored in a metal tank. The bladder, made of a plastic composition, is the gas bag. As the pressurized gas fills the bag the fuel is forced out of the tank at a specific rate. In addition, this procedure insures that all the available fuel is used. The check valve in the system prevents a return fuel flow or a transmission of pressure waves from the decomposition chamber to the fuel tank. A check valve is shown in figure 6–17.

Since this power system is used to drive an alternator, a constant or as nearly constant speed as is mechanically possible is required. The controlled throttle valve will accomplish this by varying the flow of fuel to the decomposition CATALYST tank. (A CATALYST is an agent which causes a speed-up of a chemical change although not taking part in

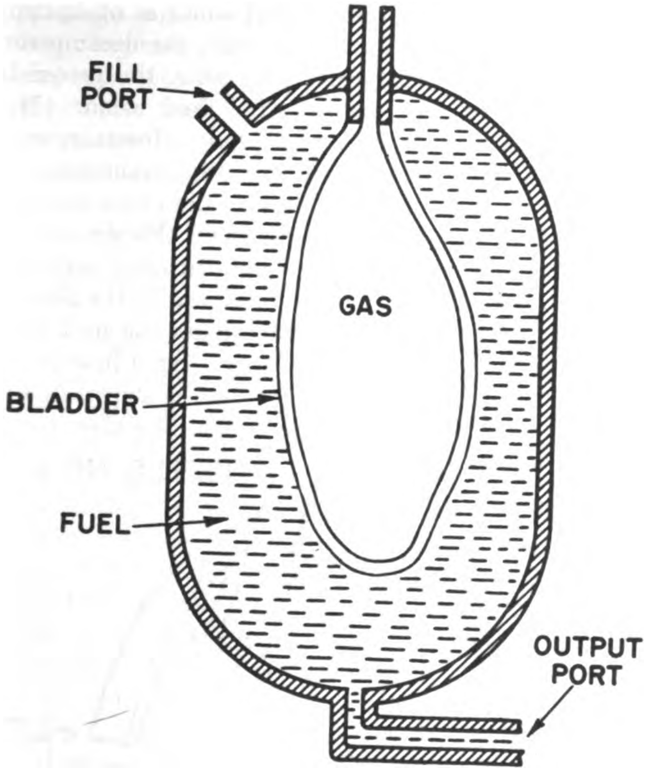


Figure 6–16.—Fuel tank.

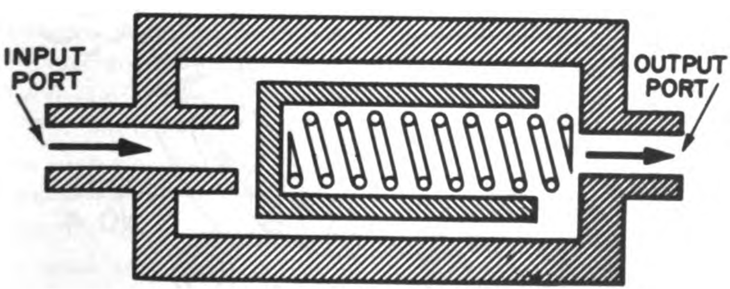


Figure 6–17.—Check valve.

it.) When the fuel, a concentrated solution of hydrogen peroxide (H_2O_2), comes in contact with the decomposition catalyst ($NaMnO_4$) sodium permanganate, the peroxide is broken down into free oxygen (O_2) and steam (H_2O). Other chemical changes take place, too. However, we are not concerned with these changes in this discussion. The fact that the reaction produces steam is the prime consideration here. The heat energy produced in this process is as much as can be efficiently used in small turbines, hence there is no need to burn the free oxygen produced by the decomposition of the peroxide. The turbine takes the heat energy and converts it to mechanical energy. An illustration of the type of turbine which might be used is shown in figure 6–18. This turbine is a single stage, impulse turbine.

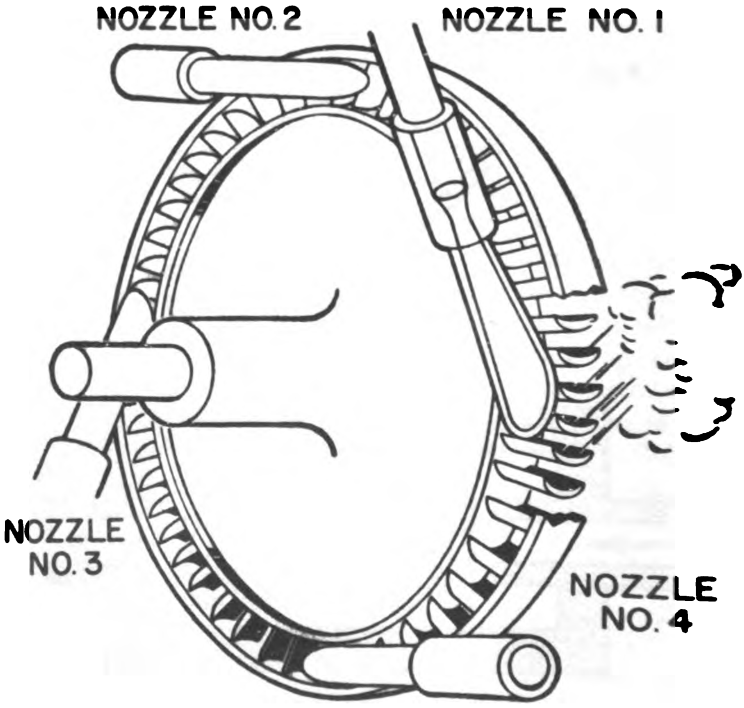


Figure 6–18.—Impulse turbine.

Single stage in that there is only one rotor and one set of nozzles. Impulse meaning that the operation of the turbine depends upon the impulse of the steam jet.

Because the shaft speed of the turbine is so very high it is necessary to use a set of reduction gears between the turbine and the alternator and the hydraulic pump.

STATIC SOURCE OF POWER BATTERIES

We have thus far discussed the dynamic sources or prime movers for auxiliary power supplies (APS). A static source of energy is the battery. This source may generally be divided into two types—DRY CELLS or primary batteries and WET CELLS or storage batteries. The former has the characteristic of being usable only until the chemical components or active ingredients are consumed while in the storage battery the active ingredients may be restored after they are consumed by recharging. These storage batteries may be of two types depending upon the electrolyte used, namely, lead-acid which uses a dilute sulfuric acid solution and the nickel-cadmium type which uses a potassium hydroxide solution. A thorough discussion of lead-acid batteries is contained in *Basic Electricity* (NavPers 10086) chapter 2. Because the discussion of nickel-cadmium cells is not fully covered there, it will be taken up in this text.

NICKEL-CADMIUM BATTERIES.—This type of battery represents a relatively new method of producing electrical energy through chemical processes. Unlike the lead-acid battery the electrolyte for the "Ni-Cad" is an alkaline solution and the material used in plate construction is different.

The electrolyte does not enter into chemical reaction with the plates as does the sulfuric acid in the lead-acid battery. The purity of the electrolyte is important. Potassium hydroxide has a tendency to absorb carbon dioxide from the air and as a result potassium carbonate would be formed. This solid collects on the plates of the battery and increases the internal resistance. For this reason the cells are con-

structed as described later, with air tight vents which allow gas to escape but prevent air from entering the cells.

In relation to the lead-acid battery the "Ni-Cad" possesses the following advantages:

1. Requires a short preparation (charging) time (on the order of one or two hours).
2. Has a longer charged stowage life.
3. Smaller in size and weight.
4. More rugged mechanically.

The following description of the operating principles and construction details are quoted from the Sonotone Corporation Brochure SA–130 dated 1955.

PRINCIPLES OF OPERATION

"DURING CHARGE.—The active material of the negative plate is cadmium-oxide. When the charging current is applied, this material gradually loses its oxygen and becomes metallic cadmium. The active material of the positive plate is nickel-oxide. This is brought to a higher state of oxidation by the charging current. As long as the charging current continues, these changes take place until both materials are completely converted.

Toward the end of this charging process, and during overcharge, a Sonotone cell will gas. This is a result of electrolysis of the water component of the electrolyte. The gas created at the negative plate is hydrogen and that at the positive plate is oxygen. The amount of gas created is dependent upon the charging method employed.

The cells will accept a charge at temperatures ranging from −65° to +165 F. The electrolyte does not enter into any chemical reaction with either the negative or positive plates. It acts merely as a conductor of current between them and there is no significant change in its specific gravity. Because the electrolyte is a conductor only, there is no shedding, flaking or loss of any active material from the plates. The capacity of the cell remains virtually constant through its life."

"**During Discharge.**—A chemical action in reverse of that which occurs during charge is immediately initiated when electrical energy is withdrawn from the cell. The negative plate gradually gains back oxygen, and the positive plate gradually loses oxygen. There is no gassing on discharge due to this interchange of oxygen.

This process results in the conversion of the chemical energy of the plates into electrical energy. The rate at which this conversion takes place is primarily determined by the external resistance imposed by the electrical circuit to which the cell is connected. Due to the type of cell construction, there is extremely low internal resistance within the cell. The chemical nature of the electrolyte and its specific gravity remain unchanged during discharge. The relative constancy of the cell voltage during discharge is due mainly to these factors."

"**Charging Methods.**—The construction of the Sonotone sintered-plate cell is such that it is readily adaptable to standard charging systems. These include constant voltage, constant current, stepped constant current or float charging. Most efficient performance from constant voltage or constant current will result when the charging rate is such that 140 percent of the rated capacity of the cell is returned in a maximum of three hours."

"Sonotone batteries will accept a full charge at temperatures as low as −65° F."

The methods which may be used for charging nickel-cadmium batteries are as listed above; however, you should know the meaning of each and how they are accomplished. The CONSTANT CURRENT METHOD of charging consists of keeping the current supplied to the battery at a constant level throughout the time of charge by voltage control. This may be done by varying the source voltage or by inserting a resistor in series with the source voltage and varying the resistance value. The latter method is illustrated in figure 6–19. In using this method the source voltage will be in-

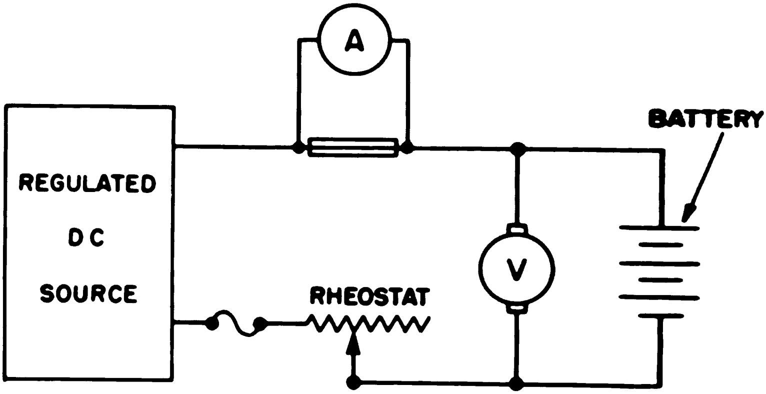


Figure 6–19.—Battery charging.

creased as the battery reaches full charge. The following formula will illustrate this:

$$E_{source} = \text{battery} - IR_{internal}$$

"I" is constant and the internal resistance of the battery is constant; therefore, as $E_{battery}$ goes from zero to some finite value E_{source} must increase in order to charge the battery.

The CONSTANT POTENTIAL or CONSTANT VOLTAGE method of charging is employed by the Navy for nickel cadmium batteries. A constant fixed potential is supplied to each cell. When a discharged battery is first put on charge the current drawn by the battery is in excess of the normal rate. However, this condition is short lived and as the battery accepts the charge the current is reduced. The capacity of the battery is restored in a short time as a result of the high initial current.

ROTATING ELECTRICAL EQUIPMENT

The prime movers discussed in the beginning of the chapter are used to drive the dynamic sources of electrical energy. For the most part many of the generators, both a-c and d-c are discussed in *Basic Electricity* (NavPers 10086). The equipments illustrated there are much larger than those

employed in missiles, but the underlying principles are common to all types, and it is this information which is of importance to the trainee, YOU. Those types of generating equipment which are not covered in the basic texts will be taken up in this chapter. The principles of rectification equipment and voltage regulation are explained in *Basic Electronics* (NavPers 10087).

An alternator which may be used in the missile field employs FLUX SWITCHING or variable reluctance principles. You will remember from your study of chapter 14 of NavPers 10086 that a-c generators are of two types—the revolving armature and the revolving field types. These are explained as follows: the armature of the former revolves in a stationary magnetic field and the output picked off from slip rings. The latter has a stationary armature (the stator) and a rotating magnetic field, the output being taken off the stator. These types are conventional a-c generators.

FLUX SWITCHING GENERATORS

The type to be explained in this text has neither a rotating field magnet nor rotating coils. The only moving part is a soft iron rotor. Figure 6–20 shows a cross section of a flux switching generator. Note the construction—a toothed rotor, two permanent magnets and two output coils arranged on a U-shaped lamination of soft iron. Note specifically that the rotor has six poles and the stator has four. When the rotor is in the position shown in (a) of the figure, two poles line up with two poles of the stator. The other pair of stator poles face the slots in the rotor. The rotor poles are spaced 60° apart, the stator poles must have 1½ times this spacing or 90°. It is important to note also that the magnets both face the same direction, that is the north poles are opposite each other looking horizontally across the top. Flux lines will then flow as shown in (a) of the figure.

When the rotor is rotated 30 degrees in a clockwise direction, the stator poles formerly providing a flux path will now be facing an air gap and the other pair of stator poles will

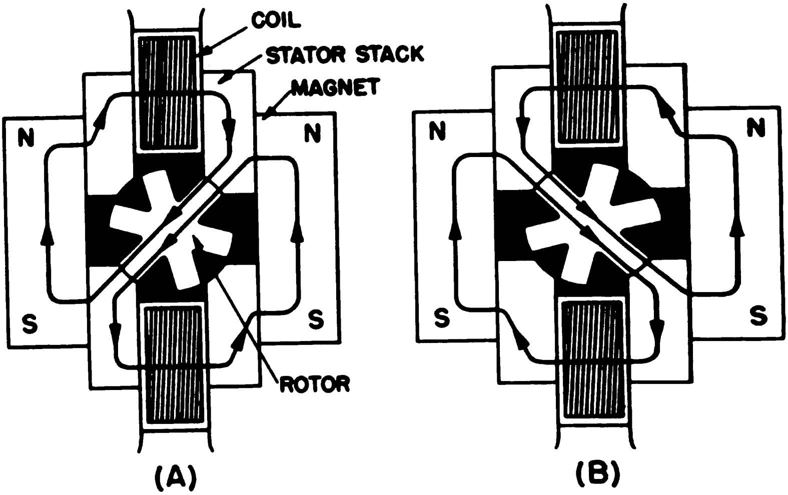


Figure 6–20.—Flux switching generator.

be carrying the flux path which is reversed in direction. Rotating the rotor another 30 degrees will cause another reversal. These two steps are shown (b) and (c) of the figure respectively. The flux path will SWITCH for every 30 degrees rotation of the rotor. If coils are wound around the field structure, a current will be induced in the coils. The frequency of the output will be equal the number of poles on the rotor multiplied by the number of revolutions per minute divided by 60 to give the frequency in cycles per second. Note that it is the number of poles and not the number of PAIRS OF POLES as in a conventional generator that determines the frequency. Thus the frequency of this type generator is twice that of a conventional generator. The output power is essentially doubled since a given amount of flux produces twice the amount of voltage as a result of doubling the frequency.

DYNAMOTOR

The dynamotor takes a relatively small d-c voltage from a source (battery) and converts this voltage by generator

action into a high voltage. The machine is essentially a d-c motor and generator mounted or wound on a common form and contained within a single housing. The field coils or strator windings are used to provide the magnetic field for both the motor and generator section. The armature or rotor has two sets of windings both of which are wound on the same core and mounted on the same rotating shaft, however, the input and output, motor and generator leads, are fixed to separate commutators. A functional diagram of a dynamotor is shown in figure 6–21. The single heavy line represents the motor winding. Relatively high current from the low voltage source flows through the field coils and the motor winding of the armature, setting up a magnetic field around both. The coils are wound in such a manner that the fields interact and thus cause the armature to rotate.

The high voltage winding represented by the fine lines between the fields is wound on the same armature and rotates with the motor winding. When turning, the high voltage winding cuts the lines of force of the common field and generates a voltage which is collected by the brushes at the high voltage commutator. The greater the number of turns in the high voltage armature winding the greater will be the output voltage.

The motor illustrated in figure 6–21 is a shunt wound machine since the armature and field windings are connected

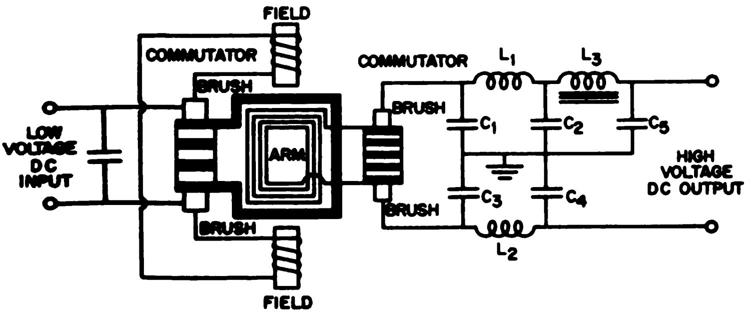


Figure 6–21.—Functional diagram of a dynamotor.

in parallel. This has the desirable characteristics of keeping the speed constant during changes in load. In some applications a series field may be incorporated in order to give a high starting torque and to reach an operating speed quickly. This field would then be shorted out to obtain the speed regulation of the shunt winding. A motor of this type with both series and shunt windings is referred to as a compound motor.

The rotor of this dynamotor may have up to four generating coils the outputs of which are led to four separate commutators. The general rule is not to exceed four output voltages since the wiring and commutation problems become impractical.

The output voltage or voltages from the dynamotor are usually filtered to eliminate interference from high frequency currents caused by sparking brushes. The filter is a combination of chokes and capacitors as shown in figure 6–21. The Chokes L_1 and L_2 present a high impedance to RF energy and the capacitors C_1, C_2, and C_4 present a low impedance path to ground for this RF energy.

Commutator ripple similiar to the ripple experienced in conventional a-c rectifiers is filtered out by capacitor C_5, and the inductor L_3. This inductor is usually of high value and as shown is an iron-core choke. The capacitor across the input to the motor section reduces arcing between the commutator and brushes.

INVERTER

INVERTERS are machines which consist of a d-c motor coupled directly to an a-c generator within a single housing. The d-c motor, when connected to a source of voltage, drives the alternator which in turn generates an a-c voltage. In most cases the d-c armature and the alternator field windings are wound in the same rotor shaft while the d-c motor field and alternator outputs (armature) windings are wound on the stator.

The d-c motor portion is essentially a shunt-wound motor. High starting currents and a low rate of acceleration are

characteristics of shunt-wound machines. To avoid these effects large inverters employ a series starting winding. When the machine approaches its normal rated speed, relays disconnect the series winding and connect the d-c input directly to the d-c armature and the shunt winding. In doing this the motor runs as a shunt wound motor which has the desirable constant-speed characteristics. In some machines small compensating and commutating pole windings are used in series with the motor armature, but these windings have no effect on the shunt motor action.

The d-c motor converts electrical energy into mechanical energy and drives the alternator. The d-c load current drawn by the motor depends upon the a-c load on the alternator. The motor speed is controlled by a speed control governor. In most cases the speed control governor is a device which automatically varies a resistance in series with the motor shunt field. The speed of the d-c motor is inversely proportional to the strength of the field. Therefore the regulator automatically decreases the resistance of the shunt field as the motor speeds. The opposite is true when the motor tends to slow down.

The generated a-c voltage is proportional to the speed of the rotor and the strength of the alternator rotor field flux. The controlled frequency of the a-c output is usually fixed at 400 cycles per second. This frequency is a function of the number of poles in the alternator field and the speed of the motor. The number of independent voltages, or phases, in the output is determined by the number of windings on the stator of the alternator. In some inverters both single-phase and three-phase outputs are obtained from the same machine. Others are equipped to supply either one or the other of those mentioned.

Figure 6–22 is a simplified schematic diagram of a typical inverter. The three-phase alternating current at 115 volts may be obtained across the delta-connected output terminals when approximately 27.5 volts of direct current is applied across the input terminals of the motor.

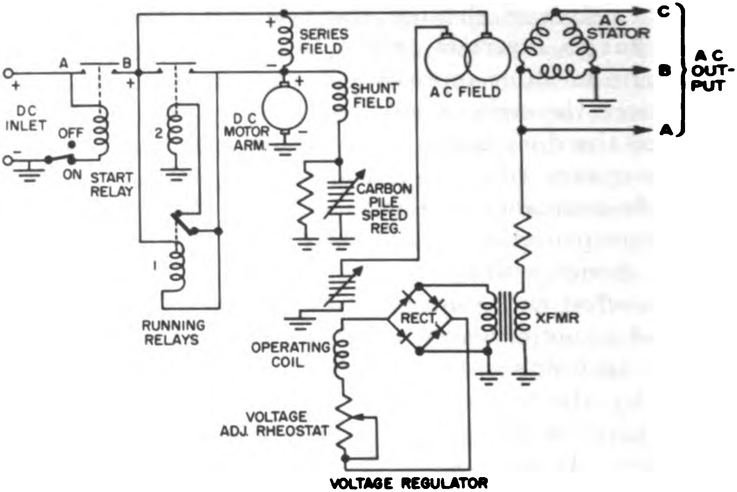


Figure 6–22.—Schematic diagram of an inverter.

When d-c input is applied and the main control switch is closed, the input voltage then appears at point *A* and the coil of the starting relay becomes energized, closing its contacts. The input is then connected, directly to point *B* and direct current flows through the motor and its series field, starting rotation of the motor. The large voltage drop across *BC*, which is due to a high series-field current, energizes the coil of the lower running relay (1), and its normally closed contacts open. As the motor approaches its operating speed, series-field current decreases, thereby decreasing the voltage drop across *BC*, the relay is deenergized, and its contacts close.

When the contacts of the first running relay (1) close, the voltage at the positive brush of the d-c armature is then applied to the coil of the second running relay (2). This voltage is sufficient to energize the coil of the relay (2), its contacts close, and input voltage is then applied directly to the d-c armature and the shunt field, bypassing (shorting out) the series starting field. The motor then operates as a shunt-wound machine.

When the starting relay is energized, the input voltage at point *B* also serves to excite the rotating field of the a-c alternator through slip rings located on the rotating shaft. Since the alternator field is in series with a carbon pile unit of the voltage regulator, the direct current through the rotor is thereby controlled. The rotating field flux sweeps across the stationary armature windings and induces voltages in them, and three-phase a-c voltage appears across the output terminals.

A portion of the output current (output terminal *A*) is rectified through the step-down transformer and dry-disk full-wave rectifier. The rectified d-c current then regulates the current flowing in the alternating rotor field by its action in the operating coil of the regulator. The action of the carbon pile regulator is the same as that for any d-c carbon pile regulator. The voltage-adjusting rheostat is used to set the operating level of the output.

QUIZ

1. The two basic types of missile auxiliary power supplies are
   a. a. c. and d. c.
   b. chemical and battery
   c. generators and motors
   d. static and dynamic
2. A basic requirement of a missile auxiliary power supply system is
   a. fast actuation time
   b. long active life
   c. short storage life
   d. complex design
3. The primary source of energy in the pneumatic auxiliary power supply system described in the text is
   a. compressed hydraulic oil
   b. compressed air
   c. hydraulic oil
   d. water
4. A —— is employed to drop the flask pressure from 3000 psi to 300 psi for the turbine in the pneumatic system
   a. reducing valve
   b. relief valve
   c. control valve
   d. blow-off valve
5. What is the performance of a pinwheel reaction turbine a function of?
6. Dehydrators are located in the ——— of the pneumatic system to reduce the moisture content of the air
   a. air flask
   b. release valve
   c. release valve
   d. pressure reducer
7. The principal purpose of the blow-off valve is to
   a. relieve excess pressures
   b. act as a governor
   c. reduce air flask pressure
   d. seal the system from dirt
8. What are the components of a pneumatic-hydraulic auxiliary power system?
9. An air motor transforms
   a. kinetic energy to potential energy
   b. hydraulic energy to pneumatic energy
   c. pneumatic energy to hydraulic energy

10. In order to prevent hydraulic shock, a hydraulic pump and motor have
    a. an odd number of pistons and an even number of ports
    b. an air cushion suspension
    c. rubber mounting supports
11. Liquid propellants in which the fuel and oxidizer are combined in one solution are called
    a. bipropellants
    b. monopropellants
    c. self-oxidizers
    d. unopropellants
12. Liquid bipropellants are undesirable for auxiliary power supply units because
    a. low turbine inlet temperature is required by the APS
    b. their specific energy is too low
    c. they are too expensive
    d. their performance is unpredictable
13. Hydraulic pressure is obtained from a solid propellant auxiliary power supply system by means of a/an
    a. air motor
    b. hydraulic motor
    c. hydraulic accumulator
    d. gas turbine
14. What are the advantages of a nickel cadmium battery over a lead acid battery for missile use?
15. A flux switching generator employs a
    a. rotating field magnet
    b. soft iron rotor
    c. rotating coil
16. One determining factor of the output frequency of an alternator is the
    a. number of conductors in the armature
    b. number of poles in the field
    c. amount of voltage applied to the field
    d. amount of current flowing in the armature
17. A dynamotor is a/an
    a. a-c driven motor with d-c output
    b. combination of d-c motor and d-c generator
    c. d-c driven motor with an a-c output
    d. chain driven generator
18. An inverter is a
    a. motor
    b. dynamotor
    c. motor-driven alternator
    d. voltage regulator

CHAPTER 7

GUIDANCE SYSTEMS FOR SURFACE LAUNCHED MISSILES

One of the essential characteristics of the guided missile is the use of electromechanical systems for carrying out the actions of guidance and control—the processes performed by the pilot in conventional aircraft. By automatic action the missile then becomes a projectile which is able to correct its path as it flies toward the target. By thus compensating for inaccuracies in aiming and for evasive motions of the victim, its probability of striking and destroying the enemy object is greatly increased.

The four basic processes in missile guidance and control are TRACKING, COMPUTING, DIRECTING and STEERING. These processes are covered in chapter 4 of this text. The definitions of each process bear repeating, however. TRACKING is the process of continuously determining the relative position of the missile with respect to the launcher, the target, the flight path, some other reference or a combination of two or more of these. COMPUTING is the process of calculating the directing signals for the missile by using the intelligence supplied by the tracking devices. DIRECTING is the process of sending intelligence to the control units within the missile. STEERING is the process of changing the flight path. See figure 7–1 for a graphical representation of these processes.

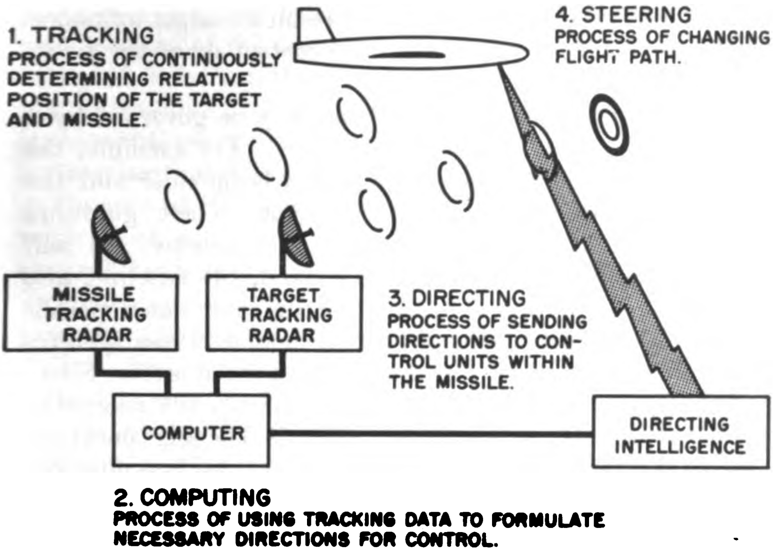


Figure 7–1.—Basic processes of missile guidance.

These basic processes occur during one of the three phases of missile flight which are the initial or LAUNCHING PHASE, the MIDCOURSE phase and the final or TERMINAL phase. These correspond to periods of time along the flight path. The initial phase of guidance is the period from firing until the missile has reached the end of boost. For instance, when a *Terrier* is initially fired it is boosted to flight speed at which time the booster is separate from the missile proper. When a *Regulus* is catapulted, the initial phase may be from the instant the catapult ram starts down the flight deck until the control plane assumes guidance control at cruising altitude. Midcourse guidance is that guidance phase from the end of the initial phase to the start of the terminal phase. This includes the major portion of the flight and it is during this phase that most of the corrections to the missile flight path, as a result of target course changes, are made. The terminal guidance phase is that phase or time period from the end of the midcourse phase to the time

of detonation of the warhead, as a result of target influence. This may be as a result of actual contact or of the proximity of the target in range.

Each of these phases of guidance may be governed by a specific system or a number of systems. For example, the initial and midcourse phase may be a beam-rider and the terminal phase an active homing type. These guidance system tapes can be separated into four groups: (1) self contained, (2) beam riding or command, (3) baseline, and (4) homing. Within each group we can again name specific systems. The self contained group includes those systems in which intelligence is entirely within the missile. Some of the systems of this group are: (1) preset, (2) magnetic, (3) inertial, and (4) stellar navigation. The self contained group is most commonly used in surface-to-surface missiles.

The beam riding group tracks the target with radar and the missile rides the beam. A detailed explanation will be given in chapter 8. In the command guidance group the target and missile are tracked independently and the missile flight path is computed from these tracking data plus constants and reference data. The flight path orders are then transmitted to the missile which moves only in accordance with the command signals.

The baseline group consists of those systems in which a navigation baseline is set up and the missile is controlled in a manner similar to that used in aircraft electronic navigation techniques.

The homing group is subdivided into three classes: (1) active, (2) semiactive and, (3) passive. In the homing system all guidance equipment is located in the missile, but the source of illumination may be in the missile (active), in a remote location (semiactive), or at the target (passive). These types will be covered in detail in chapter 9.

The selection of one of these methods for application in a particular missile is influenced by the following factors: (1) the type of target against which the missile is to be used, (2) the effective range of the missile, (3) the number of cor-

rections which must be applied during flight, (4) the nature and location of the launching equipment and, (5) the visibility of the target, that is, whether the total flight path lies within the line of sight distance to the horizon or whether its extent is great enough to make the curvature of the earth a necessary consideration.

Because of the great importance of radar in the systems with which you will be concerned, it is necessary to consider several fundamental radar techniques which are characteristic of missile guidance before describing any of the specified systems. Before reading the present section and those which follow, the reader should study carefully the material contained in chapted 14 of *Basic Electronics*, NavPers 10087, which concerns the general principles and concepts of radar and the basic types of radar circuits and components.

TYPES OF MISSILE RADAR

The radar equipments used in missile systems use one of the three methods listed in the basic text: PULSE MODULATION, CONTINUOUS-WAVE (CW), or FREQUENCY MODULATION (FM). Of these, perhaps the most frequently used is the pulse modulation, in which pulses of very short duration, time-wise, are transmitted and received. This time duration is referred to as PULSE WIDTH and is normally expressed in microseconds or tenths of microseconds. The electromagnetic radiations are located in the microwave region of the spectrum which permits the formation of narrow beams using small antennas, and also permits the use of small components in the system. The pulse modulation equipment usually operates by emitting a comparatively high number of pulses per second. The number of pulses per second emitted is referred to as the PRF or pulse repetition frequency. The use of microwave radiation and high pulse repetition frequency, together with the narrow beam of radiation, insures accuracy in range and bearing measurements. These factors also insure good resolution. BEARING RESOLUTION and RANGE RESOLUTION are the abilities to distinguish between two tar-

gets which are close together in bearing and in range, respectively.

The primary function of a CW radar is to transmit a continuous signal and to receive from the target a reflected signal which is shifted in frequency. The amount of frequency change or shift is called the DOPPLER FREQUENCY and it depends on the velocity with which the missile moves toward or away from the target. This value can be measured by a suitable detector to indicate the presence of a moving object and to reveal the closing speed of the missile with respect to the object. Two antennas are usually employed in the CW system. In most missile applications one antenna receives radar waves directly from the launching site radar transmitter. The other antenna in the missile receives reflections from the target, which is illuminated by the parent radar. The signals are then mixed in the missile guidance circuits to obtain the difference, or Doppler frequency, which reveals the target information.

With the frequency modulation method the wave emitted from the transmitter is varied in frequency at a fairly slow rate, so that each cycle differs from the preceding cycle by a small difference in frequency. If the frequency value increases at a constant rate and is then quickly returned to its initial value, a method is thereby provided for distinguishing one part of the emission from another.

In the operation of FM radar, two signals are introduced simultaneously into the receiver. One of these is the echo reflected from the target with a frequency value of f and the other is the radiated signal of f plus or minus a small increment, the latter being the signal which is produced at that particular moment by the transmitter. When these two signals are mixed in the detector circuit, a difference frequency is developed, the value of which is determined principally by the time required for the radar wave to travel to the target and return. Hence, the value of the beat, or difference frequency is an indication of the range of the target. If the transmitting and receiving antennas are highly

directional, that is, they emit and receive energy only in certain directions, the position of the target object may also be determined from the angular position of the antennas when maximum signal strength is returned from the target.

In *Basic Electronics*, NavPers 10087, naval radar equipments are classified according to use and function into the three broad classes of search, fire control, and fighter-director systems. From this point of view most of the radar equipment in missile systems can be considered as belonging to the fire control class. In the design of this kind of radar, emphasis is placed on good resolution and extreme accuracy in range and position measurement. To meet these requirements, high carrier frequencies are employed, and pulse equipments operate with high pulse repetition rates and narrow pulse widths. Fire control antennas usually employ parabolic reflectors, the reflecting surfaces of which are large in diameter compared with the wavelength of the emitted energy. This focuses the radiation into narrow beams. Antenna systems contain either mechanical or electrical devices which deflect the radiated beams in systematic scanning patterns, such as lobe-switching or conical scan, to insure precision in locating the target. Fire control receiving circuits respond to and amplify steep-sided pulses and hence are characterized by wide bandwidths. Many special circuits are included for increasing the rate and accuracy of the measurements.

The operation of fire control radar differs from that of search and other systems in that a single object is TRACKED, and the entire attention of the radar is concentrated on one target. The purpose of tracking is to determine continuously the object's coordinates of range, bearing, and elevation so as to locate it accurately in space. This operation consists principally of the two basic processes of range tracking and angle tracking.

RANGE TRACKING in missiles is usually accomplished by a group of circuits which not only measure the target range and its rate of change but also control the action of the radar

receiver, allowing it to function only during a short time interval when the desired echo signal is present. The range information is derived by the use of gate pulses which occur after a varying amount of time delay following the transmission of the radar pulse. When an echo is received that occurs simultaneously with the gate pulses, the unit automatically locks on the echo and tracks it by adjusting the time of occurrence of the gate to that of the arrival of the echo. The time delay of the gate pulses then is a measure of the target range.

Sections of the receiver in this system are disabled and no output is produced until the range unit permits the passage of the desired signal by applying an enabling voltage to the receiver circuits. By keeping the receiver inoperative except for this brief time interval, echoes from objects at ranges different from that of the principal target are excluded from the control circuits and the missile is prevented from seeking the wrong destination. Also, unwanted receptions from energy jamming transmitters as well as undesirable reflections from the sea or ground are thereby largely prevented.

Angle tracking consists of keeping the radar antenna pointed at the target to derive information concerning the angles of bearing and elevation. In missile applications of fire control radar, angle tracking as well as range tracking is accomplished automatically. The radar beam is swept over the area containing the target in such a way that the returning echoes vary in amplitude with the position of the object with respect to the axis of the radar beam. The target echoes determine the receiver output, which is converted into control voltages proportional to the error in the aim of the antenna. The error voltages are then applied to servomechanisms which adjust the direction of the antenna to cause the system to lock on the target and follow it accurately.

The techniques of range and position measurement by radar are of fundamental importance in missile guidance.

For a more detailed explanation of the principles of ranging, the reader is referred to *Basic Electronics*. To make clear the methods by which the angular error signals are derived during the process of angle tracking, it is necessary to consider the actions of the radar antenna in shaping and directing the required narrow beam and also the manner in which the energy is scanned over the target area.

ANTENNA ASSEMBLIES AND BEAM SCANNING

In the operation of guidance systems based on radar tracking, the antenna assembly performs several important functions. It contains a metallic reflector and a feed device for transmitting microwave energy in narrow beams and receiving echoes from only certain directions. Since the direction of the antenna axis is the principal reference line in determining the target location, it is necessary that the antenna be stabilized so that it points in the same direction in spite of the motion of the missile or ship in pitch, roll, or yaw. The assembly also includes some means of deflecting the beam in a regular motion to scan the target area.

In (A) of figure 7–2, a ray arriving from V strikes the reflecting surface at point A and is reflected to point F, called the FOCAL POINT of the parabola. The line AN is drawn normal to the surface at point A, or perpendicular to the tangent line. Then during reflection the angle VAN, the angle of incidence, is equal to angle NAF, the angle of reflection, so that the reflected beam passes through the focal point. The geometry of the parabola is such that all rays along parallel paths reaching the surface of the parabola, are reflected in the same manner and pass through the focal point.

The incoming rays are concentrated and brought to a point only when they enter the dish in perfectly parallel lines; and the transmission of parallel rays, as shown in (B) of figure 7–2, occurs only when the waves originate from a point source placed exactly at the focal point. In radar systems these conditions are only approximated. The sources of

electromagnetic waves are not point sources, and the beams produced are considerably wider than those indicated in the figure. And while the radiation pattern of a reflector antenna consists principally of a major lobe representing a high concentration of energy, other minor lobes are also present, indicating smaller amounts of radiation in undesired directions.

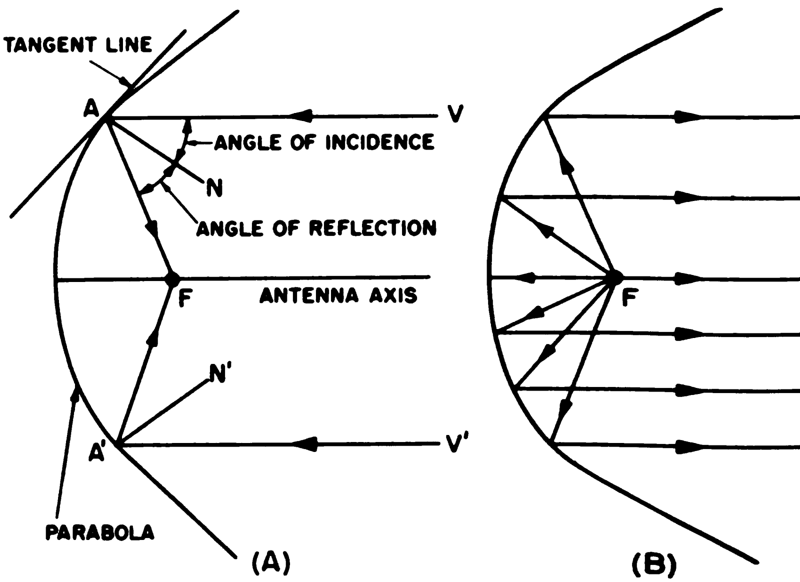


Figure 7-2.—Parabolic reflector.

In order to obtain a narrow beam in the principal direction and to minimize the minor lobes, either the reflector must be made very large or else the wavelength must be very short, so as to approximate as nearly as possible the conditions of point-source radiation. This is one of the reasons for the frequent use of microwaves in radar, since they permit the formation of beams of sufficient narrowness by reflectors of reasonable size.

Figure 7–3 represents the radiation sent out by the antenna of a fire control radar. Although the angles are exaggerated, the figure shows that if the energy returned by a target (A) hit by the center of the beam is taken as 100 percent, that returned by a target (B) one-half of 1° off the center of the beam is 95 percent. The return from a target (C) 1½° off is 80 percent, and the signal strength decreases rapidly to 40 percent at 2° (D) and is to nearly zero at about 5°.

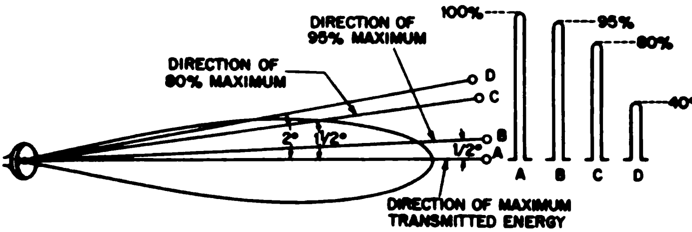


Figure 7–3.—Fire control radar antenna radiation.

The importance of the beam angle lies in the fact that it determines the accuracy with which the radar can measure the angles of bearing and elevation of the target. It also determines the angular resolution and the ability to distinguish two targets at equal ranges but slightly different bearings, since objects separated by less than the width of the beam return echoes as though they were a single object.

Antenna Feeds.—Small directional antennas placed at or near the focal point are used to feed energy into parabolic reflectors and to collect the returning radar echoes and convey them to the receiver. The primary feed element may be either a small dipole or a specially constructed section of waveguide, terminated in such a way that the radiation is directed into the reflector. The feed system may be either REAR FEED, in which the waveguide extends through the reflector from the rear, or FRONT FEED, in which the waveguide

approaches the reflector from the front and releases energy directly into it. Two frequently used types of rear feed elements are shown in figure 7–4. In figure 7–4A, a dual aperture horn called a CUTLER FEED is illustrated; and in 7–4B a dipole termination on a waveguide is shown.

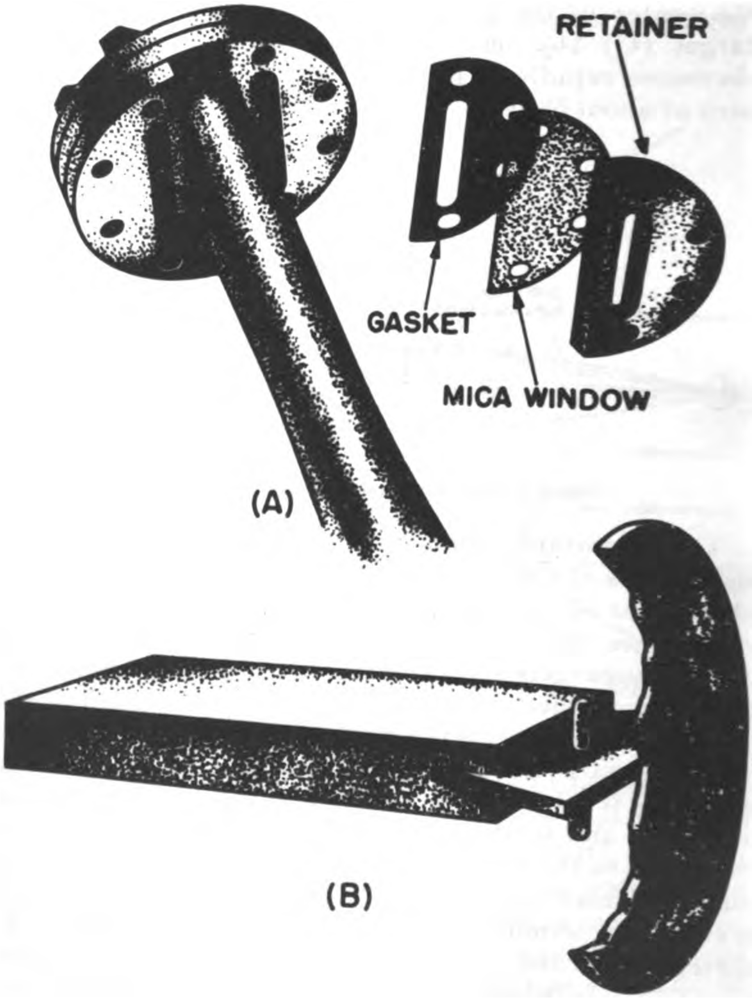


Figure 7–4.—Antenna rear feed elements.

The Cutler feed operates by radiating the energy back toward the parabolic surface through the two openings situated in the termination of the waveguide. In the dipole assembly shown in figure 7–4B the tapered section serves as an impedance-matching device. It also improves the radiation pattern by decoupling the outer wall of the waveguide from the dipole element. Front feed systems usually employ horn radiators, composed of lengths of waveguide opening in flares through which the electromagnetic energy is released toward the reflecting dish.

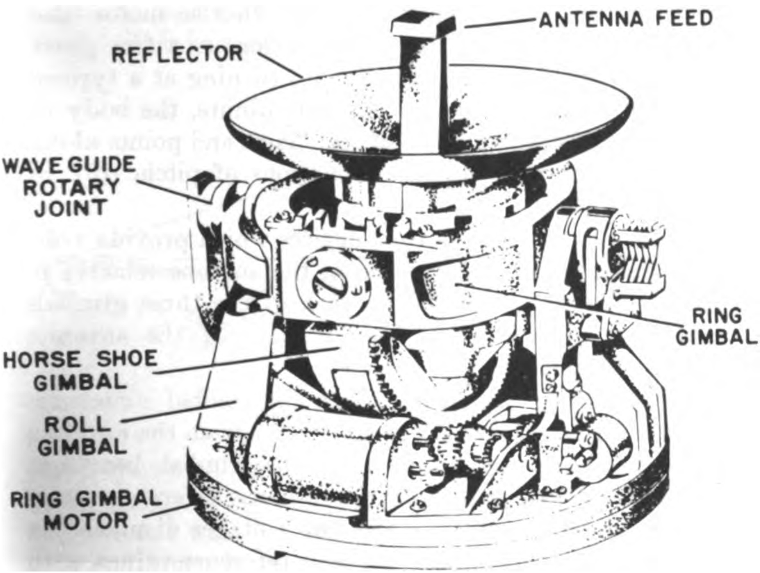


Figure 7–5.—Antenna assembly.

Antenna Assembly.—An antenna similar to those used in missile tracking radars is shown in figure 7–5. The drawing represents no particular unit but shows the general features of the antennas employed in missiles which carry a complete radar system.

At the center of the assembly is placed the parabolic reflector and a Cutler-type rear feed horn. Most of the additional components shown are needed for controlling the initial antenna aim and for stabilizing its position. Stabilization is required in some cases so that the antenna axis lies along a fixed line in space, serving as a reference for measuring the bearing of the target in the establishment of an intercept, or collision course.

The reflector and associated equipment are suspended on three gimbals, or supporting frames, equipped with bearings which allow the antenna freedom to move in three dimensions. The reflector body is the basic stabilizing device since it is driven by an internally mounted electric motor and rotates at a high speed. Hence it functions as a free gyroscope. Supported by the gimbals and turning at a typical speed of about 10,000 revolutions per minute, the body of the reflector maintains its axis of spin fixed, and points along the same line despite the missile motions of pitch, roll, or yaw.

Position pickoffs, or electrical devices which provide voltages dependent upon the position of the antenna relative to the missile body, are located on each of the three gimbals and permit the continuous measurement of the antenna direction with respect to the vehicle.

Waveguides are contained within the gimbal structures and conduct the microwave energy to and from the antenna through rotary joints situated at the gimbal bearings. Within the antenna gyro body a two-phase reference alternator is mounted which generates two voltages displaced in phase by 90°. These voltages serve as reference values with which the echo signals are compared.

In addition to beaming the energy, the antenna deflects the radiated beam in the systematic scanning motion called conical scan.

Conical Scan.—The term "scan" denotes the motion of the radar beam in space while searching for a target or while determining its position. Many scanning motions

are used, but the method usually employed in missile applications is conical scan, in which the radiated lobe is rotated so as to generate a cone with its apex at the antenna.

Conical scanning can be accomplished in several ways. In the assembly shown in figure 7–5 it is produced by rotation of the reflector. The dish is mounted with its center offset slightly from the center of rotation. The feed horn remains fixed (thereby maintaining the polarization unchanged) and as the dish rotates the focal point of the parabolic surface describes a small circle about the feed point. As a result of this motion the beam spins in space in the manner indicated in figure 7–6. Other methods of producing a conical scan are used in which the reflector remains fixed and the feed (either horn or dipole) is rotated.

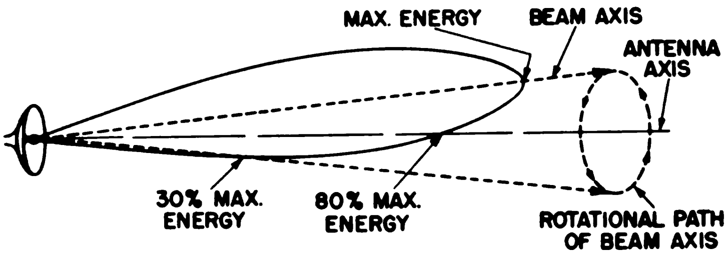


Figure 7–6.—Conical scan pattern.

As shown in figure 7–6, during automatic tracking the beam points at an angle of a few degrees with respect to the antenna axis. A target located exactly on the antenna axis continuously receives a constant amount of the radiation, in this case about 80 percent of it. However, a target situated away from the axis receives radiation that varies in strength from 100 percent to less than 30 percent, depending on its displacement from the line along which the antenna is pointed. This is shown more clearly in figure 7–7, in which the return signals from a target that is 1½° off the antenna axis are contrasted with the echoes from a target

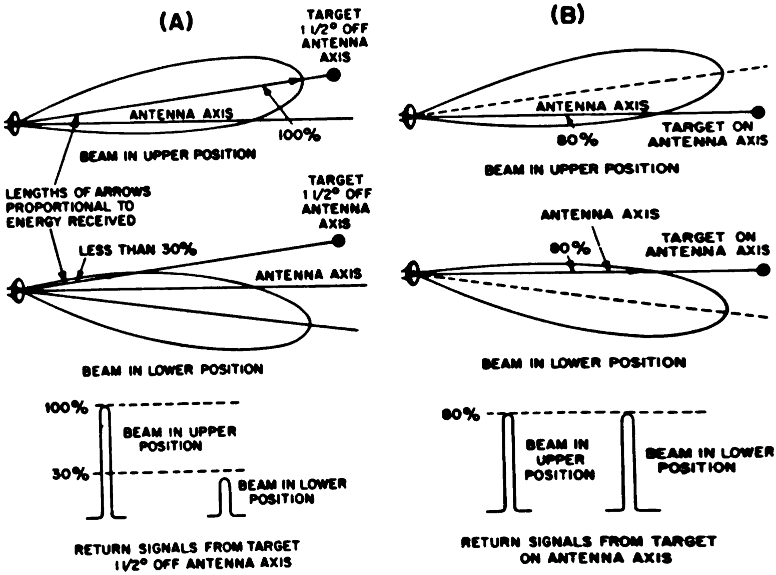


Figure 7–7.—Echo signals with conical scan.

on the axis in 7–7A; the return signals from a target on the antenna axis are shown in 7–7B.

The axis of the antenna does not change appreciably during the time required for several spins of the beam, hence the direction of the lobe after one-half revolution changes from the upper position shown in figure 7–7 to that shown in the lower position. As the beam rotates between those extreme positions, the echo signals vary gradually in strength, as is shown in figure 7–8, so that the returned pulses are amplitude modulated in proportion to the displacement of the target from the antenna axis. The figure shows only eight echo signals per revolution for convenience in illustrations, but in an actual case many more are present, the number for each revolution being determined by the ratio of the pulse repetition frequency to the rate of rotation of the beam.

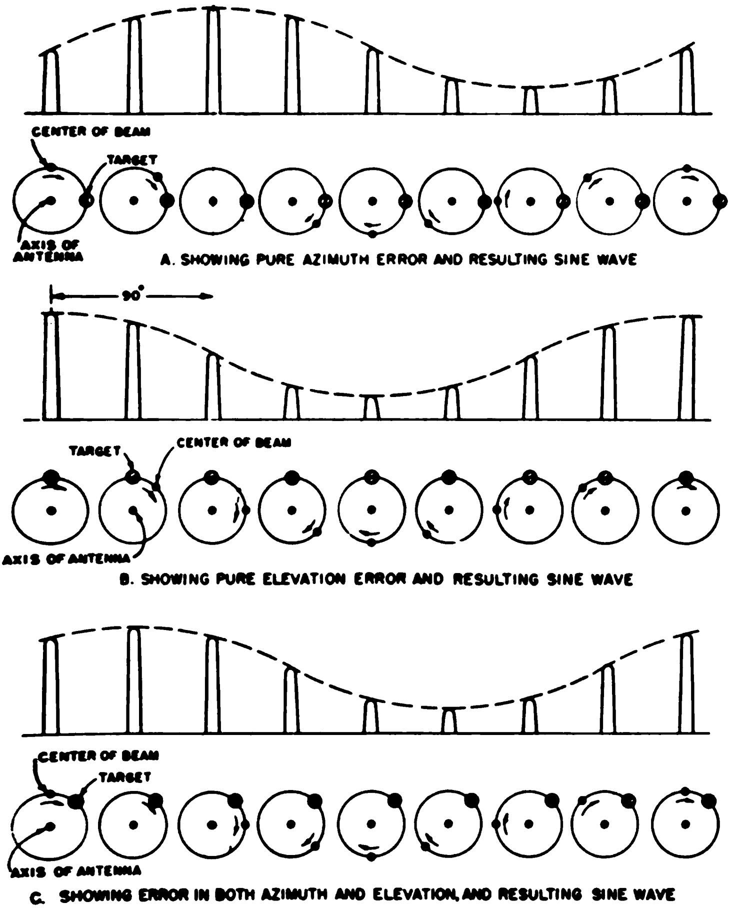


Figure 7–8.—Signals produced by bearing and elevation errors.

The bearing and elevation angles of the target with respect to the antenna axis are indicated by the phase of the variation in returned signal strength, as indicated in figure 7–8. In (A) of the figure is shown the signal resulting from an error in bearing only; while that produced by an error in elevation alone is shown in (B). By comparing the two diagrams, it can be seen that the variation repre-

senting bearing error is displaced in phase by 90° from a signal produced by a pure elevation error. The error signal resulting from a combination of bearing and elevation errors is shown in (C) of the figure, in which the variation in amplitude reaches a maximum value somewhere between the moments of maximum for pure bearing or pure elevation errors. Any other position of the target results in a similar error signal, the phase of which is determined by the amount of the bearing and elevation errors present.

In order to convert the signals returned from the scanning process into usable control voltages for tracking the target, it is necessary to compare the modulation on the pulses with the output of the two-phase reference generator which is synchronized with the rotation of the antenna. The two reference voltages are displaced in phase by 90° so that one is in phase with a pure bearing error signal and the other with a pure elevation error.

When the axis of the antenna points directly at the target, the echo pulses are all of equal amplitude, as is shown in (B) of figure 7–7. In automatic tracking, the error control voltages are applied to servomechanisms which position the antenna so as to zero the error signals and maintain the antenna aim fixed on the target.

Lobe Switching.—In the operation of some missile radar systems, the bearing angles of stationary targets are determined by the scanning process called lobe switching. A lobing antenna produces two beams, one at a time, switching rapidly from one to the other. The directions of the two differ by a small angle equal to about one beamwidth, and signals are returned as each beam strikes the target. When the two echoes are compared, the strength of one with respect to the other depends upon the position of the target in relation to the antenna directions, as shown in figure 7–9.

The returning signals are equal in strength only when the reflecting object lies on the line bisecting the angle of intersection of the two lobes. If the target is situated on either side of this line, the echoes differ in amplitude in such a way

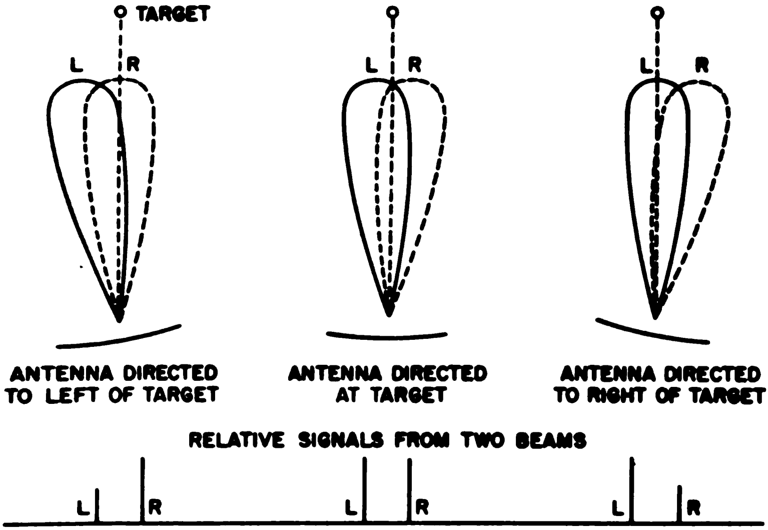


Figure 7–9.—Lobe switching.

as to indicate whether it is to the left or to the right of the antenna direction. The two signals are compared visually in some fire control radars, but in missile systems they are compared electrically and fed directly into circuits that adjust the antenna direction for equal amplitudes of the received signals.

In order to conserve space, the components in this type of system are arranged in very compact assemblies and subassemblies, and most of the electronic tubes and related parts are of subminiature construction. Usually, the larger elements are those which are involved in the generation, control, and transmission of superhigh-frequencies; and these are grouped together to comprise the MICROWAVE ASSEMBLY.

TYPICAL MISSILE RADAR SYSTEM

The basic components of a radar system similar to those used in missiles employing active homing guidance are in-

dicated by the block diagram in figure 7–10. In this kind of guidance the missile carries a complete and independent radar set which both transmits energy to illuminate the target and receives echoes from it. The diagram represents no specific radar set, but is intended to exhibit the fundamental operation of this specialized type of equipment.

The individual members of the microwave assembly are the magnetron, which originates the microwave energy; the duplexer, containing the TR and ATR tubes which act as a switch for connecting the antenna first to the magnetron and then to the receiver input; one or more mixers; the klystron oscillator; the antenna assembly; and various sections of waveguide.

Closely associated with the action and functioning of the microwave components are the SYNCHRONIZER, which supplies the timing pulses for initiating the numerous processes of the entire system, and the MODULATOR, which supplies high voltage to the magnetron, allowing it to operate for very short intervals of time to produce the pulses of microwave energy.

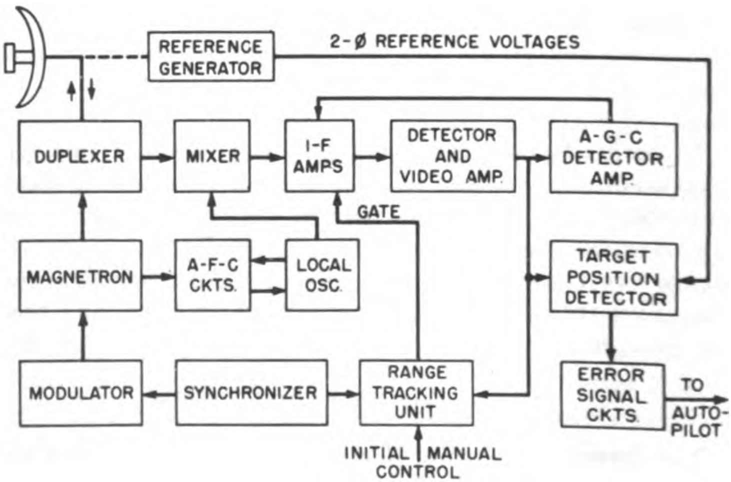


Figure 7–10.—Radar block diagram for active homing.

The superhigh-frequency waves from the magnetron are coupled to the antenna through the DUPLEXER. This unit has the same function described in *Basic Electronics*, but in missile applications it is usually of special construction and is small in size, being similar in appearance to the unit illustrated in figure 7–11.

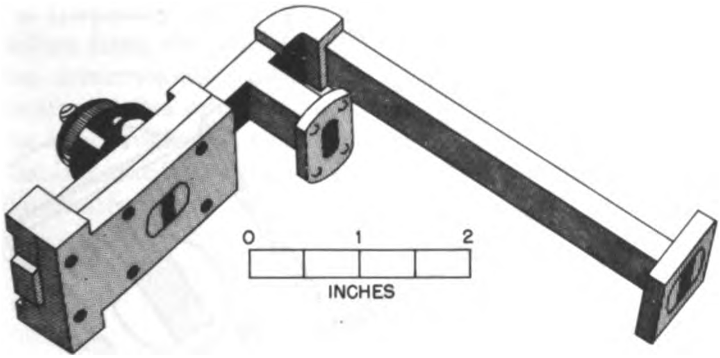


Figure 7–11.—Duplexer unit.

The antenna, usually similar to the unit shown in figure 7–5, is equipped as a rule with a waveguide feed, and is mounted on gimbals. The gimbals are formed from sections of waveguide and serve both to support the antenna and to conduct electromagnetic energy to it for transmission, or from it to the duplexer and then to the mixer during reception. The antenna is usually covered by a specially designed surface called a RADOME. Since target tracking antennas are located in the nose of the missile, the radome is aerodynamically designed with good physical strength, and yet does not interfere seriously with the propagation of the radar waves. Most of the missile radomes are constructed of nonmetallic materials so that they do not distort or reflect the radar beam; they must be handled with care.

In the MIXER the output of a local oscillator is combined with the echo signals to produce the intermediate-frequency

(i-f signal), the frequency of which is in the order of 60 megacycles. The physical construction of a miniature wave-guide-type mixer is shown in figure 7–12.

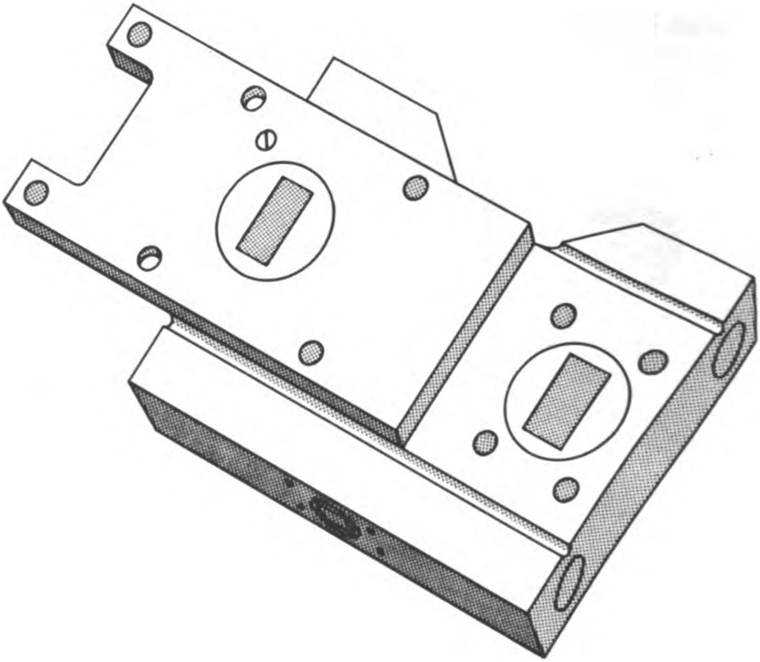


Figure 7–12.—Mixer construction.

The receiving section not only detects the returned signals, but also extracts from them the information necessary for guiding the missile. Since conical scan is usually employed, the information is in the form of amplitude and phase variations of the received echo pulses. And in addition to the usual receiver circuits, such as i-f amplifiers, detectors, video amplifiers, and automatic-gain-control (AGC) circuits, the system illustrated in figure 7–10 also contains a TARGET POSITION detector and a section labelled error signal circuits.

After conversion, amplification, and detection of the received pulses, the output of the video amplifier is applied to the position error detector which measures its amplitude and phase by comparison with the output of the two-phase reference generator. The resulting signals are applied to the error signal amplifiers for application to the autopilot. An important part of the receiver is the AUTOMATIC-FREQUENCY-CONTROL (AFC) system, the function of which is to adjust the frequency of the local oscillator continuously so that it differs from the magnetron frequency by the exact value of the intermediate frequency. The RANGE TRACKING UNIT receives pulse information from the video circuits and from the synchronizer, and produces the gate pulses which gate the intermediate-frequency circuits to provide range discrimination.

QUIZ

1. What are the four basic processes of missile guidance and control?

2. Directing is the process of
   a. calculating missile flight control signals
   b. sending intelligence to the missile
   c. changing the missile flight path
   d. determining missile relative position

3. What are the three phases of missile flight?

4. Which of the following groups of guidance systems are usually employed in surface-to-surface missiles?
   a. Self-contained
   b. Beam riding or command
   c. Base line
   d. Homing

5. Pulse width and pulse repetition frequency are characteristics of which of the following radars?
   a. Continuous wave
   b. Frequency modulated
   c. Pulse modulated

6. Continuous wave radar detects moving targets by means of
   a. the pulse-echo process
   b. signal intensity comparisons
   c. modulated radar waves
   d. the doppler principle

7. In frequency modulated radar, ———— is an indication of target range.
   a. the detected frequency difference
   b. the pulse-echo return time
   c. antenna triangulation
   d. the summation of the transmitted and the received frequency

8. In order to obtain good resolution and accuracy in range and position measurement, missile fire control radar is designed with
   a. high frequency, low PRF and narrow pulse width
   b. low frequency, high PRF and narrow pulse width
   c. high frequency, high PRF and narrow pulse width
   d. low frequency, low PRF and wide pulse width

9. What are the two basic forms of tracking which are accomplished by missile fire control radar?

10. A missile fire control radar antenna reflector generally approximates the shape of a/an ———.
  a. parabola
  b. ellipse
  c. hyperbola
  d. hyperbolic parabaloid

11. Antenna feeds are placed at or near the ——— of parabolic reflectors.
  a. upper perimeter
  b. focal point
  c. lower perimeter
  d. center.

12. The number of echoes received per revolution of a conical scan is determined by the
  a. ratio of the transmitted frequency to the rate of rotation of the beam
  b. ratio of the pulse width to the rate of rotation of the beam
  c. ratio of PRF to the rate of rotation of the beam
  d. ratio of the focal length to the rate of rotation of the beam

13. Position of a target in a conical scan is fixed by the
  a. amplitude signal
  b. phase angle and amplitude signal
  c. phase angle

14. The scanning process in which the antenna produces two beams, one at a time, switching rapidly from one to the other is
  a. beam switching
  b. comparative scanning
  c. lobe switching
  d. dual scanning

15. In the active homing guidance system, the missile homes on
  a. target echoes of a signal originating in the missile
  b. target echoes of a signal originating from a ship or other remote station
  c. signals originating from the target

16. What is the effect on the accuracy of a radar of making the antenna beam angle narrower?

CHAPTER 8

BEAM RIDER GUIDANCE SYSTEM

Now that we have covered the principles of tracking radar in the previous chapter, we can continue with the types of guidance systems with which you will be most concerned. The first of these is the beam riding system. This is a system of guidance in which a beam of radiation is propagated from a guiding point and is of such a nature that adequate information is conveyed to a guided missile to keep it automatically centered in this beam. The system can be designed so that it will form a "control line" for three dimensional guided missile control or a "control plane" for two dimensional guided missile control.

The most promising type of control beam for medium and short range guided missiles is a radio frequency beam, generated and propagated by use of radar techniques. Several types of tracking radars are available for beam riding.

For some applications it may be desirable to use the control beam for target tracking. In this situation, under proper operating conditions, the target, the missile, and the control beam source are in a straight line, and the guided missile will cover a line-of-sight course. Such a system offers the advantage of high traffic handling capacity, which is limited only by mutual interference of guided missiles in the beam, and no further control of the missile will be necessary after it has once entered the control beam.

An alternative beam-riding system consists of a control beam and a separate tracking device such as automatic tracking radar. With this system the guided missile can be made to follow any trajectory by inserting a computer between the target tracking device and the control beam for directing the latter. This system is limited by its low rate of fire since only one missile at a time can travel in the guide (control) beam and follow a course determined by the computer; an exception is when a line of sight trajectory is made. Another disadvantage is that the addition of the two units (target tracking device and computer) increases the size, weight, and complexity of the system, and introduces the possibility of additional errors.

In the beam riding system the three phases of missile flight are as previously defined, initial, midcourse and terminal. The initial phase in this case might be considered the capture phase for in some applications of this system the missile must first be captured before it may be guided. The small angle which the guidance beam subtends makes this kind of initial phase difficult to accomplish. However, by using, in effect, two systems, an autopilot system and a beam guidance system, we can effectively guide the missile to the target. The automatic pilot is a system of automatic controls which holds the missile in any desired heading, brings it back when displaced from that heading, and keeps the missile accurately stabilized in pitch and roll. The autopilot system can be used during the capture phase, and the beam rider system for the remainder of the flight.

Just after leaving the launching rack the missile will not be in the effective region of the radar control beam; the autopilot conducts it along a predetermined course which intersects the line of the control beam by the time the acceleration or boost phase ends. Some type of timing device, for example a stepping relay, operates at the end of the boost phase and thus transfers control from the autopilot to the beam-rider guidance system.

It is the function of the servo system to convert the electrical command signals supplied by the other two sys-

tems into wing deflections. This is accomplished by the action of vacuum-tube circuits and magnetic amplifiers which supply signals to the wing-actuating servomechanisms. The latter are usually hydraulic units, although pneumatic systems are employed in some missiles for deflecting the control surfaces.

In each of the two control phases just described the missile is controlled in pitch, yaw, and roll. The components which supply the wing commands are described in the following pages; and since the autopilot function occurs first in the sequence, the units which are active in this portion of the flight are considered before those which operate in the beam-guidance phase.

AUTOPILOT PHASE

While the propellant is burning in the boost phase, the beam-rider missile flies as a ballistic rocket, except that the automatic pilot, operating through the servo system, corrects for any deviation from the desired course. Control of the missile in the autopilot phase is based on the output signals of sensing instruments such as gyroscopes and accelerometers, which detect changes in heading and attitude and the rates at which these changes take place. When undesirable motions of the weapon occur, these instruments then supply corresponding error signals to a summing amplifier, which combines the various signals and converts them into input voltages for the wing-actuating units. These deflect the wings, or control surfaces, so that the missile is steered along the required course.

A discussion of the details of the gyroscope and other sensing instruments and of the units of the servo system must be reserved for a later chapter. It is necessary here to consider only the kinds of units involved and their essential functions in the autopilot operation. In general, these units enable the autopilot to supply two kinds of control—pitch-yaw correction and roll control. The former governs the heading of the missile and corrects the flight path

with respect to the pitch and yaw axes. The latter control governs the rotation of the airframe about the longitudinal axis.

PITCH-YAW CONTROL.—The block diagram in figure 8–1 gives an example of the units contained in an autopilot pitch-yaw control system. In this arrangement the pitch and yaw error signals originate in the outputs of three groups of instruments: a free gyroscope, two rate gyroscopes, and two accelerometers. These measure changes in heading, rates of change, and acceleration at right angles to missile flight path, respectively. The output voltages of each instrument are applied to a summing amplifier, which combines the separate voltages into the pitch and yaw error signals for the servo system.

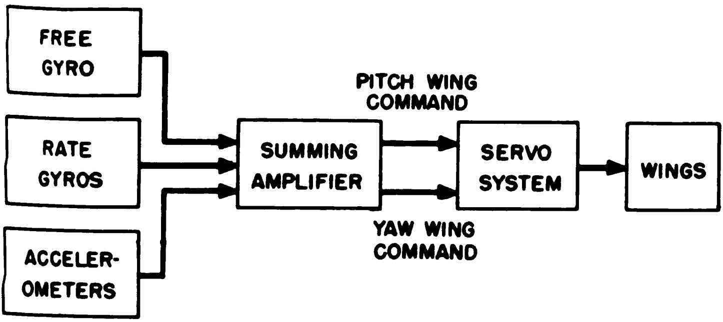


Figure 8–1.—Autopilot pitch-yaw control system.

The free gyro provides a fixed reference line in space directed along the axle of the rotating gyro wheel, the basic part of the instrument. The wheel is mounted in gimbal rings which permit freedom of movement for the rotor in three dimensions. And as a result of gyroscopic forces, the spin axis of the rotating wheel remains unchanged in direction, even when the missile pitches and yaws.

At launching, the free gyro is uncaged in a position so that the axis of the rotor lies along a line parallel with the desired missile heading. This direction, which is also par-

allel with the longitudinal axis of the missile at launching, is maintained by the gyro during flight, thereby providing the required reference line against which changes in missile heading can be measured.

When the vehicle deviates from the preset heading, two potentiometers (one for pitch and one for yaw) attached to the free gyro gimbal rings then develop voltages proportional to the amplitude of the changes in heading. These voltages are combined with additional signals from the rate gyros, which detect the rates of rotation about the lateral axes. Also added are the signals from the accelerometers which represent the components of acceleration at right angles to the flight path.

The signals of the free gyro, when applied to the summing circuits, produce wing commands which tend to bring the missile back to the original course. The output signals of the rate gyros and the accelerometers act in opposition to the free gyro signals and provide feedback action which opposes any missile motion in pitch or yaw. By adding the feedback signals, damping of the missile response is provided and the tendency to overshoot or oscillate about the desired course is thereby minimized.

In the ideal case the missile flies along the preset course and the outputs of the control instruments are zero. But in practice slight misalinements of the wings or tail fins, unbalance in the control surfaces, air turbulence, or other disturbances cause the missile to swing from the required path. The control instruments then initiate corrective actions by supplying input voltages in the summing circuits.

The summing amplifier and servo sections of the block diagram (fig. 8–1) are common to both the autopilot and the beam-guidance functions; the principal difference in the two phases is that the input signals are derived from different sources. The summing section contains three channels, corresponding to the three types of error voltages involved, that is, pitch, yaw, and roll. In the summing circuits the error signals are combined, amplified, and lim-

ited. During autopilot operation, the free gyro and feedback voltages are combined, or summed, by applying them to resistance networks in the appropriate channels. The resultant voltages are amplified and applied to the limiters. The purpose of the limiting action is to prevent excessive deflections of the wings; and to accomplish this, the error voltages are clipped if they exceed the safe maximum value but remain unaffected by the limiters if the error voltage is less than this critical voltage.

The principal units of the servo system are amplifiers and wing-actuator assemblies. The servo amplifier, like the summing section, contains three channels which accept the pitch, yaw, and roll error signals. After amplification the voltages are applied to the wing-control servos, which convert the electrical impulses into wing motions of the proper direction and amplitude.

Roll Control.—In some surface-launched missile systems the autopilot causes the weapon to rotate during the thrust phase in a manner similar to the spin given a bullet in flight. The rolling motion increases stability by reducing the effects of undesirable lateral acceleration. Such acceleration may result from offset thrust of the rocket motor, from unbalance in the missile control surfaces, or from similar forces which cause sideward motion. If the missile body is caused to roll, the direction in which the lateral force acts is then constantly changed; and the resulting displacement is distributed throughout 360 degrees during one rotation of the airframe. As a result, the deviation in any particular direction is reduced and the correction required of the autopilot is considerably minimized. The principal effect on the flight path of adding roll to the undesirable sideward thrust is that the missile then flies on a corkscrew track, or tight spiral, about the required course.

The units of the autopilot which produce and govern the rolling motion are represented in figure 8–2. In this system the signal applied to the servo units to cause the motion is derived from two voltages fed to the roll channel of the sum-

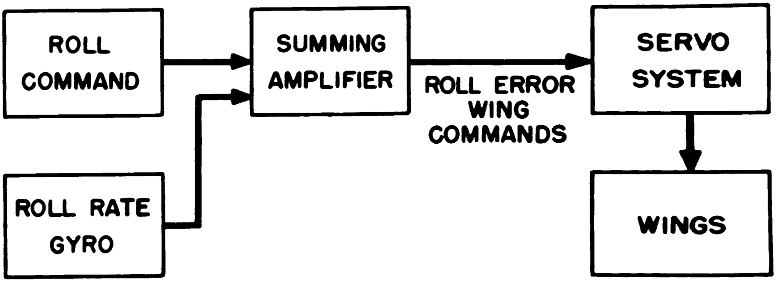


Figure 8–2.—Autopilot roll control system.

ming amplifier. These are the roll command, a fixed bias voltage, and the output of a rate gyroscope which provides a signal proportional to the rate at which the missile rotates about the longitudinal axis.

The roll command acting alone results in rotation. The roll rate signal is subtracted from it to provide feedback: and the resultant is then the roll error signal which is applied through the servo amplifier to the wing-actuating units. The wing units respond by operating one or more pairs of wings differentially: one member of the pair is deflected in a direction opposite to that of the other member. This type of deflection, which is similar to the motion of the ailerons of an aircraft wing, supplies the required rolling action of the airframe.

The control of the missile path in pitch, yaw, and roll by the autopilot instruments and the servo system continues to the end of the boost phase, when the operation of the timed switching device transfers the control system to the guidance phase. The gyros and accelerometers which supply the guidance information during acceleration of the weapon are then disconnected from the input terminals of the summing amplifier, and a new set of components and circuits are attached automatically. These develop the wing commands for the servo system by receiving and processing the emissions of the companion radar.

BEAM-GUIDANCE PHASE

After the autopilot has conducted the missile into the narrow pencil of rays transmitted by the launching ship, the weapon becomes a true beamrider; and its success in finding the target then depends upon the response of its guidance circuits to the radar signals. Before considering the missile circuits, however, it is first necessary to understand clearly the actions of the parent radar in providing two essential factors of the guidance process. These are: first, the required course to the target; and second, a reference system which enables the missile circuits to measure the weapon's position in space with respect to this course.

The path along which the missile must fly is defined by the tracking operation of the radar. Prior to launching and throughout the boost phase the fire-control antenna is directed automatically by the tracking equipment so that the conically scanning radar beam follows the target and retains it at the center of its cone of scan. The axis of the scanning cone, an imaginary line in space connecting the tracking antenna and the instantaneous position of the rapidly moving target, then provides the required missile course.

The second factor, a coordinate system for the missile circuits, is supplied by the beam in the form of special guidance signals. These are added to the other emissions of the radar and serve as markers which identify the position of the BEAM as UP, RIGHT, DOWN and LEFT, with respect to the scan axis. This intelligence means "fly down," "fly left," "fly up," and "fly right" respectively. An example is given in figure 8–3, which illustrates a system in which the guidance signals are dual pulses emitted at regular intervals during the circular sweep of the beam.

In the figure, the path of a point on the radar beam is represented by the circle, which is traced some 50 or 60 times per second to accomplish the scanning process. The missile guidance signals, which supply the required space reference system, are the four sets of dual pulses emitted during each scanning cycle and which divide the circle of scan into four

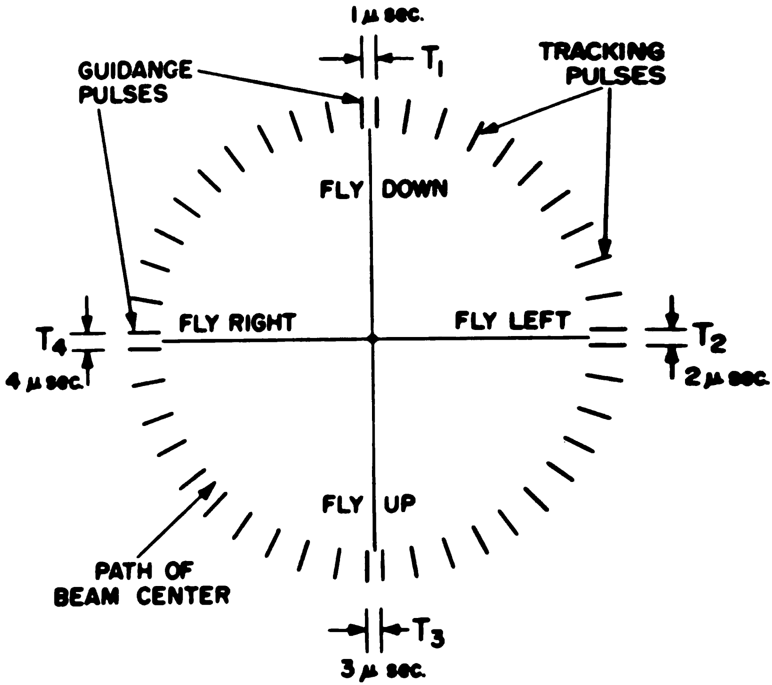


Figure 8–3.—Tracking and guidance pulses.

equal sectors. Occurring at a much higher rate than the guidance signals are the tracking pulses, the regular emissions of the fire control radar, which are returned as target echoes and so enable the tracking equipment to keep a circle of scan centered on the object of interest.

The TRACKING pulses, which are so essential in the overall operation, supply no information directly to the circuits of the missile. These operate solely under the direction of the dual guidance pairs. When received by the weapon, the GUIDANCE signals can be identified and one set distinguished from another since in each pair the two pips are separated by a different time interval. For example, the leading edges of the pulse pairs labelled T_1 might be separated by an in-

terval of one microsecond; while the remaining pairs, T_2, T_3, and T_4 might be spaced at two, three, and four microseconds respectively. Upon reception, the various pairs can then be identified by the time intervals involved and separated into four groups of signals corresponding to FLY DOWN, FLY LEFT, FLY UP, and FLY RIGHT.

The double pip signals illustrated in figure 8–3 represent only one of several forms used in beam-rider systems for conveying information to the missile. In some, the controlling radar supplies the up-down-right-left reference data by frequency modulating the tracking pulses. The pulse rate or pulse repetition frequency is varied periodically and completes one cycle of change while the radar beam is sweeping once around the scanning cycle; hence the various positions of the beam can then be identified at the missile by the instantaneous frequency of the signals received. In other systems single rather than double pulses are transmitted, and each of the four key positions on the scan circle is associated with a particular pulse width. While the details of the circuits differ according to the kind of signal supplied by the companion radar, the missile equipment is operated along the same general lines in each case; and the principle involved can be easily understood by using an example based on time-coded dual pulses.

The missile circuits use guidance signals to find and follow the correct course by the method illustrated in figure 8–4. In the process, the radar signals are received and demodulated, and the resulting pulses are separated according to the time spacings into four channels. After considerable amplification, the signals corresponding to opposite positions on the scanning circle are compared; that is, FLY UP signals are matched with FLY DOWN signals and FLY RIGHT with FLY LEFT. The relative amplitudes of the voltages indicate the position of the missile with respect to the scanning circle; and the comparison of signal strength serves as a basis for producing the appropriate wing commands when the heading needs to be corrected.

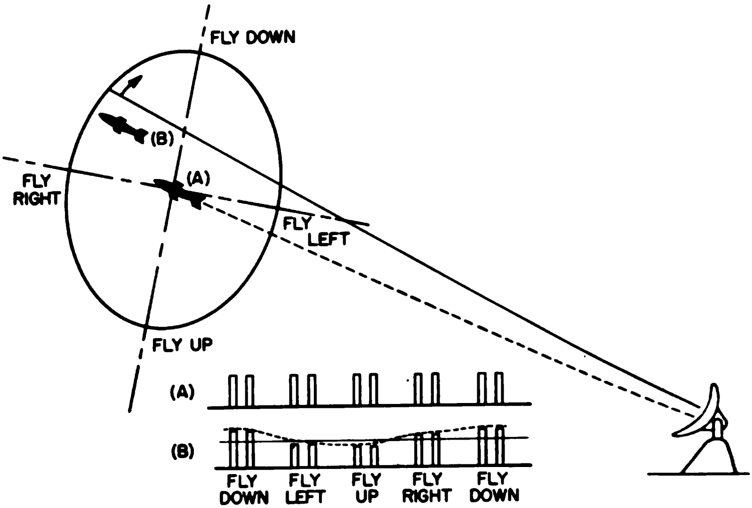


Figure 8–4.—Guidance by coded pulses.

Consider the case shown in (A) of figure 8–4 when the missile is flying along the scan axis. It is then equidistant from the beam positions at which all guidance signals are transmitted, and all four are received with equal strength. The guidance circuits produce no wing command in this case since no correction is necessary or desirable.

When the missile swings from the proper course, as in (B) of figure 8–4, it is then nearer the beam when the beam UP pulses are transmitted than when the beam DOWN signals occur; hence the former are received in greater strength. Also, the beam LEFT pulses are stronger than the beam RIGHT pairs. After comparing the opposite sets, the guidance circuits respond to the inequalities by developing two wing-command voltages. These mean "fly down" and "fly right" to the servo system, and they are put into effect by the wing-actuator units until the guidance pulses are again received in equal strength. This signifies that the missile has regained the course and is following the scan axis to the target.

THE GUIDANCE COMPONENTS

The process illustrated in figure 8–4 is carried out by the guidance components, which, like the autopilot units, supply two types of control. The first, which controls the heading of the missile, acts to reduce its displacement from the scanning axis by governing lateral movements about the pitch and yaw axes. The other, the roll axis control, banks the missile to obtain maximum lift from the wings and to equalize the lifting forces over the wing surfaces. The guidance components providing these types of control are shown in figure 8–5.

The system represented in the figure is suitable for operation with dual pulse guidance signals. The radar pulses are converted into pitch and yaw error signals delivered to the input of the summing circuits by the actions of four sections not used in the autopilot phase. These are the TAIL ASSEMBLY, the GUIDANCE RECEIVER, the GUIDANCE AMPLIFIER, and the COMPONENT RESOLVER. The output pitch and yaw voltages are combined in the summing circuits with damping signals from the rate gyro section shown in the figure to form the wing position commands, which are converted into wing deflections by the servo system. The summing amplifier and the servo units are the same components which were active in the autopilot phase.

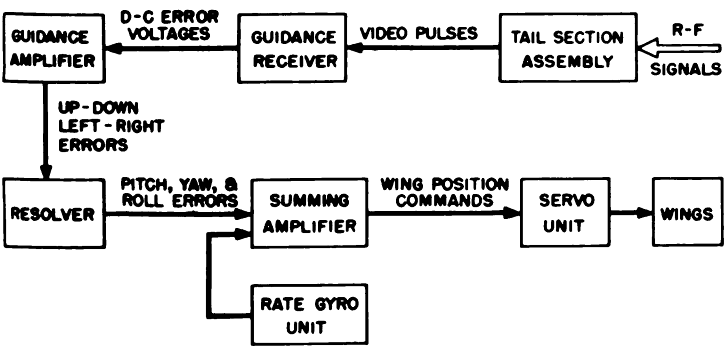


Figure 8–5.—Guidance system components.

In the guidance phase the missile is not continuously rolled as in the boost phase, but is rolled so as to aline some reference point on the airframe (such as the umbilical plug) with a line from the missile to the scanning axis. In the system in figure 8–5 roll control is achieved by comparing the pitch and yaw signals developed. The difference between the two then becomes the roll error signal. When the missile is displaced from the beam so that the pitch and yaw signals are equal in amplitude and opposite in phase, the roll signal is then zero. However, if its roll attitude is such that one error signal is greater than the other, a roll error voltage is obtained. This causes the weapon to roll until the pitch and yaw errors become equal in amplitude and opposite in phase and the roll error becomes zero. The roll signal is combined with a damping signal from the roll rate gyro to prevent oscillation about the longitudinal axis.

As indicated in figure 8–5, the conversion of the guidance pulses to pitch, yaw, and roll error voltages begins with the reception of the r-f radar emissions by the tail section of the missile.

THE TAIL SECTION ASSEMBLY.—The beam-rider tail assembly contains rear-facing waveguide antennas—usually four in number, arranged in the manner shown in figure 8–6. Each antenna is equipped with a crystal detector which rectifies the superhigh-frequency radar pulses received, converting them into video pulses. This is a special type of receiver for microwave frequencies. It is called a crystal-video receiver and an explanation of it will not be found in the basic texts which you are required to study. Normally, a radar receiver consists of an r-f amplifier which amplifies the incoming r-f energy. The amplified r-f is mixed with a local oscillator frequency and an i-f frequency is obtained. This i-f frequency is amplified and the video signals are detected from it. In the crystal-video receiver these processes are omitted and the crystal detects the video signal directly. The use of this type of receiver, however, results in an appreciable loss of sensitivity. By use of hi-gain video am-

plifiers the video pulses can be built up to a usable value but, as a result, there is a loss in the pulse shape. These disadvantages can be tolerated in this case. The advantages gained are many in the guided missile. Some of these are: reduction in power requirements, components can be smaller in size, omission of the requirements for a stabilized oscillator, and a reduction in the number of components required.

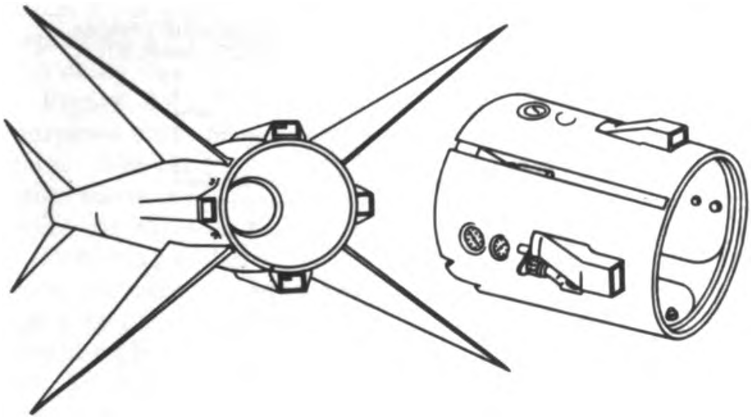


Figure 8-6.—Beam rider tail assembly.

A T-R switching tube associated with each antenna-detector assembly protects the sensitive crystal from burnout when the missile is near the transmitting antenna during launching. The T-R tubes short out pulses large enough to damage the crystals but pass the smaller pulses received during beam-rider operation. The output circuits of all the detectors are paralleled, and the signals produced are combined and applied to video amplifiers contained in the assembly. After passing through the amplifiers, the signals are then connected to the next stage, the guidance receiver.

THE GUIDANCE RECEIVER.—This section of the system, shown in figure 8-7, separates the video pulses and applies them to the fly UP, fly DOWN, fly RIGHT, and fly LEFT channels. The process is carried out by means of more video amplifiers, a demodulator, and a group of filters. After re-

ceiving considerable amplification in the receiver video circuits, the pulses are separated by demodulators; the output of each is then filtered, resulting in four d-c voltages. Each of these is proportional to the amplitude of the guidance pulses received in one of the four positions of the radar at which guidance emissions are sent. A simplified block diagram of a demodulator designed for separation of dual guidance pulses is shown in figure 8–7A.

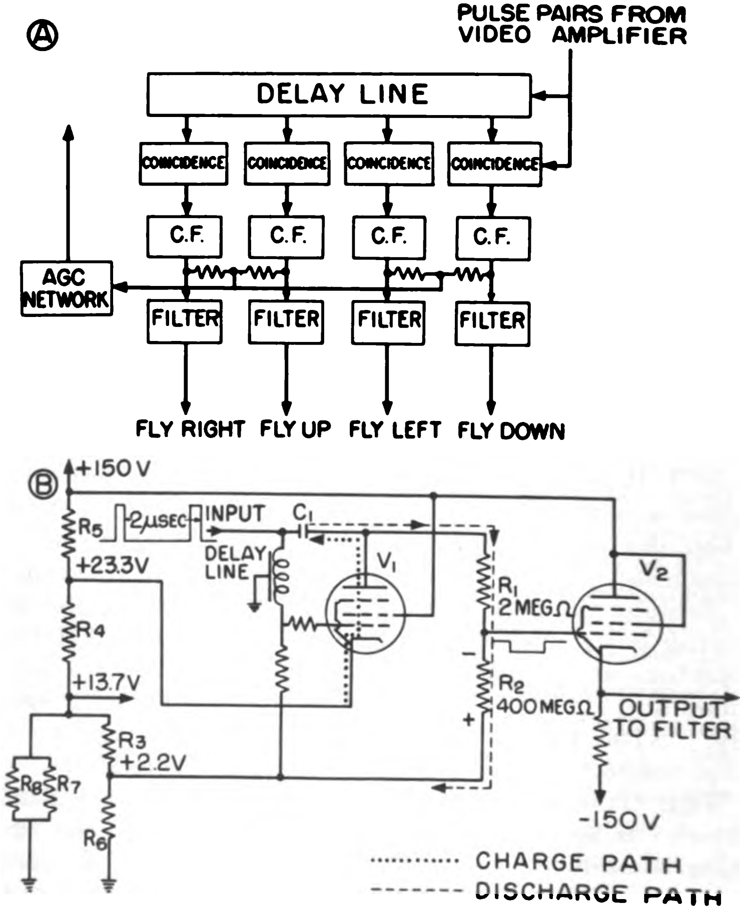


Figure 8–7.—Demodulator circuits.

The sorting, or separating, process can be accomplished by use of a delay line and four coincidence gate tubes. The delay line is made up of four sections with each section so designed as to give one microsecond delay to the input pulses. Each section of the delay line is connected to that channel which controls fly right, up, left, and down respectively. The fly right pulses are separated by four microseconds in the example—hence the delay for this signal will be four microseconds or the entire delay line. The fly up pulses are separated by a three-microsecond delay, or three sections of the delay line in use, and so forth for the other pulse pairs.

Figure 8–7B is a simplified diagram (for explanation purposes only) of a coincidence gate circuit, using a pentode tube. For the explanation of coincidence circuit operation only one section (2 μsec) will be used, as each section operates the same with a different delay time for each.

Referring to figure 8–7B, V_1 is normally biased to cut-off, with the cathode approximately 21 volts positive with respect to the control grid. The screen is connected to 150 V and the plate is connected to B through the divider network, $R1$, $R2$, $R3$, $R4$, $R5$. The screen acts as the plate of the tube for initial conduction because the plate is practically at ground potential when the tube is cut off.

When the first pulse of the 2 μsec pulse-pair arrives at the junction of the delay line and $C1$, two things occur: (1) the pulse starts down through the delay line, and (2) $C1$ tries to charge through $R1$, $R2$, but is unable to do so because of the short pulse width and the long RC time of $C1$, $R2$. Two μsecs later the second pulse of the pulse-pair arrives at the junction of the delay line and $C1$. At this time the first pulse strikes the grid of $V1$ and the tube goes into instantaneous conduction. This action causes $C1$ to charge instantly through $V1$, which acts as a short circuit to charge the capacitor. When the pulse subsides, $V1$ cuts off; $C1$ now starts to discharge through $R1$, $R2$ and at the junction of these two resistors builds up a long flat negative pulse (due to the RC time of $C1$, $R2$) to vary the conduction of the cathode follower $V2$.

If the missile is in the "fly down" sector of the scan, these pulses will be stronger than they would be if it were in the "fly up" sector. The "fly down" pulse pairs being stronger will cause the capacitor C_1 to charge to a greater value than a similar capacitor in the "fly up" sector. As a result of the greater charge, a greater negative output will be developed across R_2 to 400 megohm resistor. The three other channels are all working at the same time with different outputs from each depending on the missile's position in the scan. The action of the cathode follower is to present an impedance match between the 400 megohm load of the coincidence gate tube and the guidance amplifier. The filter net work removes any high frequencies from the output of the cathode followers. The voltages from the filter contain the error information which is applied to the next section.

Automatic Gain Control.—The AGC (Automatic Gain Control) is obtained from all four coincidence gates. It is an average voltage in respect to the strength of the radar beam and is not the result of any particular quadrant. The AGC is proportional to the distance or range that the missile is from the transmitting radar, so that weak signals will not pass undetected. This circuit works in the same manner as a normal AVC (Automatic Volume Control) as explained in *Basic Electronics*. Strong average outputs from the coincidence gate and cathode followers will result in a high AGC bias, and weaker outputs as range increases will result in less AGC bias in the first stages of video amplification.

The function of the guidance amplifier is to convert the four proportional d-c error voltages from the coincidence gates and cathode followers into two amplitude modulated a-c signals, the up-down and the right-left errors. These voltages represent the vertical and horizontal displacements of the missile from the radar scanning axis.

The amplifier unit contains two identical channels. In one, the "fly up" and "fly down" d-c signals are combined to give a resultant voltage proportional to the net vertical error.

This voltage is then used to modulate the output of an oscillator to convert the error information into an a-c form. The amplitude of the resulting modulated wave corresponds to the magnitude of the error involved; and the direction of the vertical error, either up or down, is indicated by the phase of the wave. By a similar process, the "fly right" and "fly left" d-c error values are converted into an a-c horizontal signal. The change of the information from d-c to a-c is required because of the nature of the next section. which is a special type of transformer.

The component resolver converts the up-down and right-left error signals from the guidance amplifier into pitch and yaw error voltages. See figure 8–8. These voltages are related to the relative position of the missile control surfaces. In each missile there is a pair of these resolvers. Each resolver contains three coils, two of which are in effect connected to the missile framing and the third is connected to a gimbal of the free gyro. Those attached to the frame

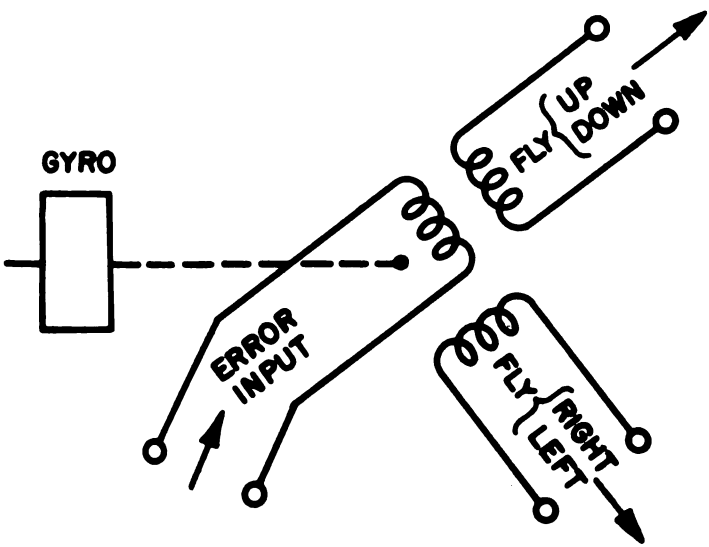


Figure 8–8.—Component resolver schematic.

are the secondary coils of a differential transformer and roll with the missile. The coil attached to the gimbal ring is the primary and remains fixed as a result of gyroscopic action regardless of missile roll. The secondary coils, in effect, rotate about the primary coil. This is represented schematically in figure 8–8. The degree of coupling between the primary coil and the two secondary coils depends upon the angle to which one is rotated with respect to the other. The error signals which are applied to the primary coil induce a voltage into the secondary which is a function of the roll angle of the missile. The output voltages from the pair of resolvers form the pitch and yaw error signals.

The function of the component resolver is illustrated vectorially in figure 8–9. The total displacement of the missile from the beam-scanning axis is represented by the vector labelled "total error." With respect to the horizontal and vertical axes provided by the radar guidance signals, the total vector is the sum of the two components, the up-down and the right-left vectors. Voltages proportional to these are applied to the primary winding of the resolver by the guidance amplifier. And two new voltages are induced into the secondary which are proportional to the pitch and yaw displacement errors shown in the figure 8–9. The pitch and yaw vectors add to give the same resultant total error, but are referred to a new set of coordinate axes, those formed by the wings themselves. The error voltages in the output are then proportional to the amount of deflection which must be given the corresponding wings in order to reduce the total error to zero.

The two signals developed at the output of the component resolver are applied to the pitch and yaw channels of the summing amplifier, where they are combined with the outputs of two corresponding rate gyros. The resultant signals become the pitch and yaw error signals which are applied to the servo system. The third signal required, the roll error, is developed by applying the pitch and yaw voltages to a resistance network in the roll channel of the amplifier. Here

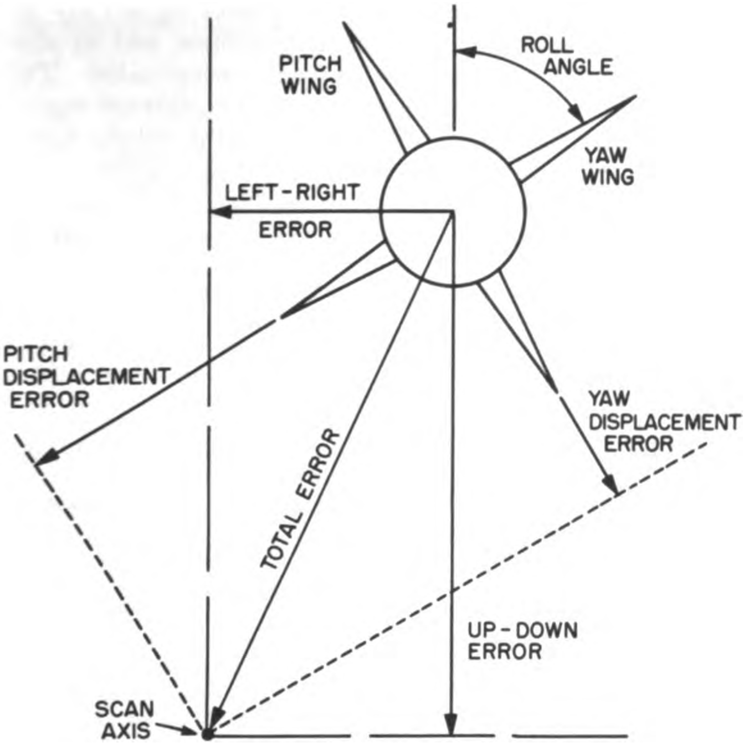


Figure 8–9.—Error signal resolution.

a voltage equal to the difference of the two signals is developed and used as the roll command voltage. It is combined with the output of the roll rate gyro and the resultant becomes the roll error command which governs the rotation of the airframe.

As in the autopilot function, the rate gyro output voltages are proportional to the missile rates of turning about the three independent axes of pitch, yaw, and roll. These voltages are employed as feedback signals of the summing circuit, and their combination with the error voltages provides a means of damping the response of the missile, thus preventing oscillation about the required course. After the

various voltages have been added, the error signals are demodulated, amplified in the servo amplifiers, and applied to the control valves of the hydraulic wing units. This operates the wings in accordance with the guidance signals emitted from the fighter radar and steers the weapon along the scanning axis to collision with the enemy target.

As shown throughout the discussion in this chapter, the techniques of radar form the basis of the operation of the beam-rider missile.

QUIZ

1. A control beam which exercises three dimensional control over the guided missile forms a
   a. control plane
   b. control triangle
   c. control line
   d. control hyperbola
2. The most promising type of control beam for medium and short range missiles is a
   a. radio frequency beam, generated and propagated by use of radar techniques
   b. radio frequency beam, generated and propagated by use of basic radio techniques
   c. radar frequency beam, generated and propagated by use of basic radar techniques
   d. radar frequency beam generated and propagated by use of radio transmission techniques
3. When the control beam is also used for target tracking,
   a. the size, weight, and complexity of the radar system are increased
   b. more than one missile can ride the control beam simultaneously
   c. the missile can be made to follow any desired trajectory to intercept the target
   d. the control beam can be programmed to allow the missile to follow an out-of-sight course
4. During the capture phase of flight, the missile is controlled by what system?
5. What is the name of the system which converts the electrical command signals from the autopilot and beam-rider guidance systems into missile wing deflections?
6. Which of the following kinds of motion control does the autopilot system provide for the missile?
   a. Yaw and roll
   b. Pitch and yaw
   c. Pitch, yaw, and roll
   d. Pitch and roll
7. What three types of instruments provide measurements for pitch and yaw control in the autopilot system?
8. Changes in missile heading are sensed by
   a. the free gyro
   b. rate gyros
   c. accelerometers
   d. pendulous gyros

9. What are the three channels of the summing amplifier?
10. The fixed bias voltage fed to the roll error channel of the summing amplifier is called the
    a. roll rate command
    b. roll error command
    c. displacement command
    d. roll command
11. The discussion in this text divides the guidance pulses into what four groups of signals?
12. What two types of control do the external guidance pulses exercise on the missile?
13. An advantage of the crystal-video receiver used in the tail assembly of the missile is that
    a. it lacks sensitivity and thereby discriminates against interference
    b. it requires less power than conventional receivers
    c. it uses simple relatively large components which are readily maintained
    d. the pulse shapes detected are well defined
14. Which of the following devices is used to protect the sensitive crystal of the crystal-video receiver from burning out when receiving strong signals?
    a. T–R switching tube
    b. Resistive phase splitter
    c. High resistance delay line
    d. Thyraton tube
15. The guidance pulses of the control beam are separated and applied to the fly up, fly down, fly right, and fly left channels in which of the following missile guidance sections?
    a. Tail assembly
    b. Guidance receiver
    c. Guidance amplifier
    d. Component resolver
16. The actual sorting, or separating, process of the guidance pulses is accomplished by which of the following circuit components in the missile described in this chapter?
    a. A delay line and four coincidence gate tubes
    b. A high band pass filter and four cathode followers
    c. Four filters and four cathode followers
    d. A reference discriminator and four filters
17. AGC bias in the first stages of video amplification of the guidance circuits is
    a. directly proportional to the distance between the missile and the transmitting radar

b. inversely proportional to the average output of the coincidence gate and cathode followers
c. determined by which quadrant of the guidance radar the missile occupies
d. inversely proportional to the distance between the missile and the transmitting radar

18. Roll control during the initial thrust phase of missile flight
a. increases stability
b. increases speed
c. is always inoperative
d. is detrimental to accurate guidance

19. Deflection of one of a pair of wings in the opposite direction from the other results in a
a. pitch movement
b. yaw movement
c. roll movement
d. all of the above

20. The component resolver converts the up-down and right-left error signals from the guidance amplifier into
a. pitch and yaw error voltages
b. roll and pitch error voltages
c. roll error voltages
d. roll and yaw error voltages

CHAPTER 9

HOMING SYSTEM OF MISSILE GUIDANCE

This is a continuation of the descriptions of guidance systems. To be able to test, repair and assemble missiles containing any of the various guidance systems, it is first necessary for you to have at least an overall general knowledge of the systems. Your concern and work with the homing system will be much the same as with the beam-riding system or the command system or with any system used in guided missiles. You are, or will be, testing the missile, analyzing defects or the causes of them, repairing the deficiencies and, in general, ensuring a reliable missile. With this in mind let us begin with a general explanation of homing systems.

The homing guidance group consists of general guidance control systems in which the path of the missile can be changed, after launching, by a device in the missile that reacts to some distinguishing feature of the target—heat, light, or the reflection of radar waves. A homing device, usually placed in the nose of the missile, picks out the target, recognizes it because of the distinguishing feature, and then directs the missile to the target. The best known systems at the present for this type of guidance are infrared (heat) radiation and radar. The range of operation of these systems is limited because the radar is not effective beyond a range of about twenty miles and the infrared system beyond a range of approximately two or three miles. Because of these limitations the homing system is not normally used

for any phase of missile guidance other than the terminal phase.

The homing group can be subdivided into three types which are: (1) ACTIVE, in which both the source which illuminates the target and the receiver which receives the returned echoes are carried within the missile; (2) SEMI-ACTIVE, in which the missile receiver utilizes radiations from the target, which has been illuminated from a source other than one in the missile; (3) PASSIVE, in which the missile receiver uses natural radiations from the target (An example of such radiations would be the heat emissions from the tailpipe of a jet aircraft).

Homing systems may be classified as either PURSUIT homing or LEAD homing systems. The pursuit homing system requires that the missile be pointed at the target at all times. Figure 9–1 illustrates this type of system. Here the beam scanner points directly ahead in the missile, and the controls are actuated so that the beam is always in line with the

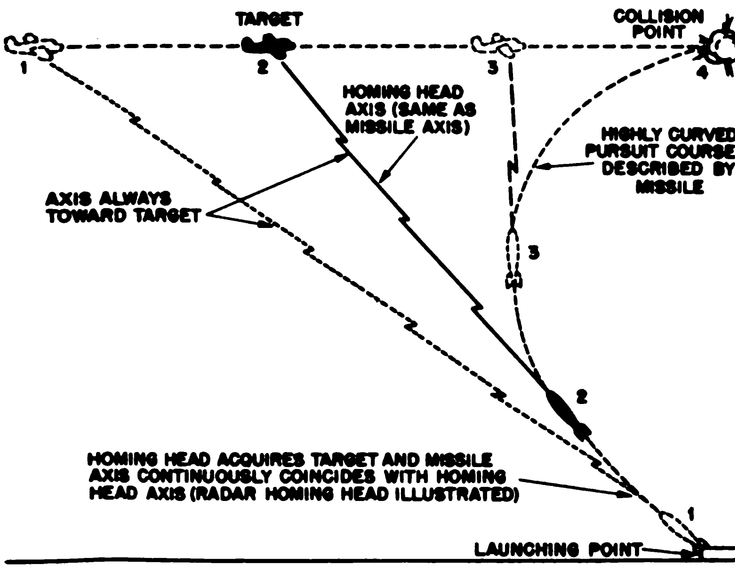


Figure 9–1.—Pursuit homing.

target. The use of pursuit homing against fast moving targets does not appear to have many applications because the accelerations required of the missile on a pursuit course become increasingly large during the last portion of the flight, the most critical part of the course.

Lead homing eliminates the difficulty of pursuit homing control. See figure 9–2. In this system the homing scanner is able to determine both the range and bearing of the target from itself. As the missile and target proceed along their respective course lines, the angle between them would normally change at some rate. The computer of the lead homing system calculates this rate of change and gives to the missile control unit a solution which will reduce this angular rate of change to zero. When this has been done, the missile and the target will have a constant bearing relative to one another and thus the missile will be on a collision

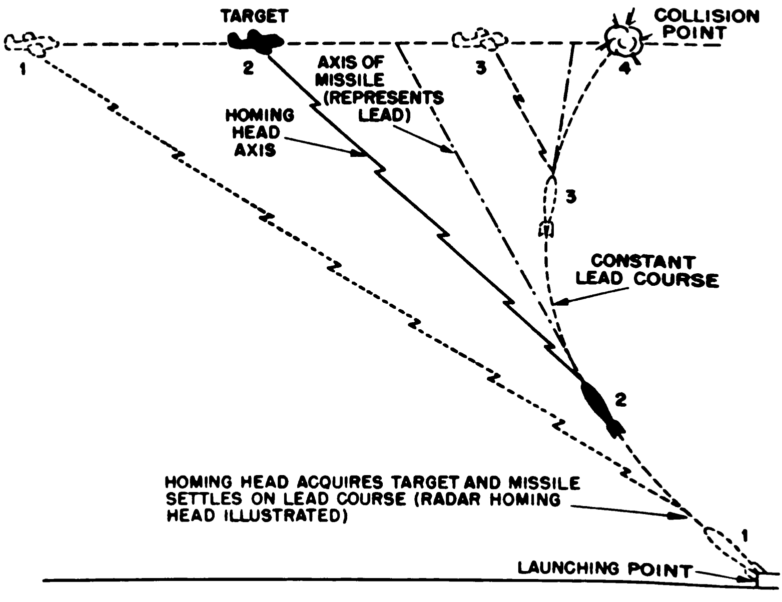


Figure 9–2.—Lead homing.

course with the target. Should the target change course, its bearing from the missile will change. The homing head will detect this change and the computer will again determine a new solution to cause the missile to take a course which will be a collision course with the target. The final and critical portion of the trajectory of the missile is a straight line and the angular accelerations required of the missile are small. The increased functions of the scanning head, however, make the design problems of the missile more complex.

FUNCTIONS OF TARGET SEEKING GUIDANCE

Target seeker guidance (homing) requires the fulfillment of several separate functions. These functions are: (1) the procurement of the information necessary to follow a prescribed navigational course, (2) comparison of that information with some standard (such as the heading of the guided missile or the previous information received), and (3) use of the results of the comparison to control the missile heading. In general, the first function will be performed by detection and amplification equipment, the second by a computer, and the third by a system of servo controls. The detection and amplification equipment may be of many forms and may have functions to perform other than target detection. Some of the additional functions are:

1. Missile stabilization—restoring the missile to its previous attitude after an external disturbance;
2. Detector stabilization—keeping the seeker head oriented with respect to some reference;
3. Target discrimination and selection—the ability to pick out one specific target because of its distinguishing feature and not be influenced by a number of other targets in the vicinity;
4. Provision for target memory circuits—those circuits which provide for a continuation of the missile flight along a path based on previous information which would cause target interception. They function should the target be momentarily obscured by clouds, etc.;

5. Automatic target tracking—refer to chapter 4 of this text.

6. Termination of mid-course guidance—may be accomplished by use of range information which actuates a switch-over relay at some predetermined range;

7. Furnishing information to some outside position—accomplished by telemetering equipment to be discussed in a later chapter; and

8. Furnishing information needed for warhead detonation—this may be accomplished by ranging techniques.

Passive radar and infrared target seekers cannot perform all these additional functions, but an active radar seeker might be able to do so.

Active homing as a system was discussed in chapter 7 of this text. Figure 9–3 is a block diagram of a representative active or semi-active system. For the most part the components shown here have been explained previously. A brief "run through" of the system will be given for review purposes.

The transmitted signal, generated in the transmitter and passed through the duplexer and antenna feed horn, strikes the target and an echo is returned. The returned echo signal passes into the receiver where the information locating the target with respect to the missile is extracted. The output of the receiver is applied to the converter which

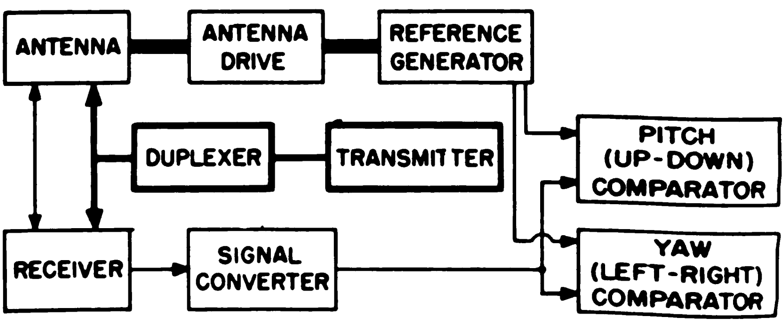


Figure 9–3.—Semi-active and active homing.

changes it to a form necessary for comparison with the reference signal originating in the reference generator. The output signals from the phase comparators are fed to the missile autopilot which in turn corrects the missile flight path to cause collision of the missile and the target.

Referring to the conical scanning system explained in chapter 7, the signal from the converter is an a-c wave whose frequency is the same as the rotational frequency of the antenna scanner. The reference generator output is an a-c wave of the same frequency as the converted signal but out of phase by 90° from the yaw axis. The comparators shown are phase comparators.

In the case of semi-active radar homing, a separate radar transmitter outside of the missile supplies energy which, after being reflected by the target, is used for homing by control equipment in the missile. Such a transmitter might be located on the ground or carried aboard a ship or aircraft. For line-of-sight paths, range might be determined by the missile using measurements of the time interval between arrival of energy from the target. Velocity might also be obtained, if desired, from the Doppler frequency shift between the main and echo signals. Greater homing range may be obtainable in many cases with this method than could be secured with a missile which radiated its own power, and the accuracy should be greater than that obtainable in beam riding since the range converges to zero. The block diagram shown in figure 9–3, with the exception of the transmitter and the duplexer, might also be representative of the semi-active homing system. For a detailed explanation of the circuitry peculiar to each system and to individual missiles refer to the instruction books on specific missiles.

INFRARED APPLICATIONS IN MISSILE HOMING

Many military targets, such as ships, factories, aircraft, and guided missiles themselves, are warmer than their surroundings and may be detected by missile guidance equipment because of the large amount of heat they emit.

Homing-guidance equipment, usually located in the nose of a missile, detects this radiation from distant objects which lie in its field of view, and transforms it by optical and electrical processes into voltage signals. These signals are then used by the autopilot in the same manner as signals from radar guidance equipment to control the flight path of the missile.

Before discussing the operation of this type of guidance equipment, the infrared system, let us discuss the nature of heat and how it is transferred from one object to another.

PROPERTIES OF HEAT RADIATION

Heat is present in any material whose temperature is above absolute zero (−273 C). It is the result of the motion of the molecules, and is a form of kinetic energy which can be transferred by only three processes—conduction, convection, and radiation.

In the process of CONDUCTION, the energy is transferred from molecule to molecule by actual contact. Metals, in general, are good conductors of heat. Because the molecules are farther apart in gases than in solids, and are freer to move about, gases are much poorer conductors than either liquids or solids.

CONVECTION is the process in which heat is transferred by moving of a heated substance, for example, when an electronic tube gets hot, the air surrounding it begins to move. The motion of the heated air is upward. This upward motion of the heated air carries the heat away from the hot tube by convection.

Our main source of heat, the sun, supplies us with energy through empty space. This is not accomplished by either conduction or convection, because these two processes take place only through a material medium such as a gas or a solid. Heat is emitted from all bodies, as well as the sun, in the form of electromagnetic waves, and is identical in nature with radio waves, light waves, and X-rays except

for a difference in wavelength. This is radiant heat, the transfer of heat by radiation.

The electromagnetic waves which produce heat in any object that absorbs them are called INFRARED waves because their frequencies are just below those of the color red in the spectrum, as shown in figure 9–4. As these frequencies are in the millions of megacycles, it is more convenient to specify them in terms of the wavelength most commonly used for these frequencies in terms of the MICRON, which is 10–6 meters. In microns, the infrared band extends from about 300 microns to 0.76 micron.

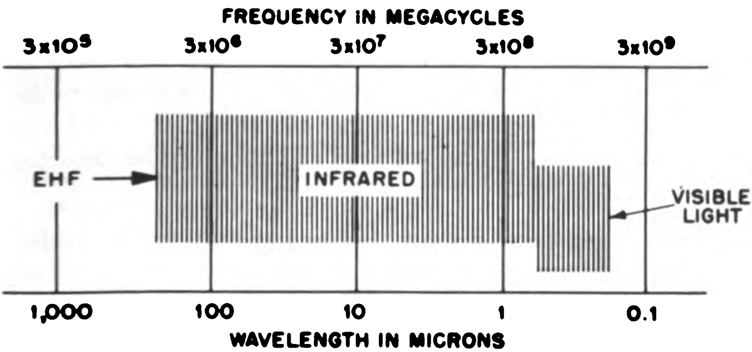


Figure 9–4.—Infrared portion of electromagnetic spectrums.

Infrared waves are emitted from any substance by the same process that radio waves are emitted from an antenna. The motion of the electrons of the moving molecules produces electromagnetic fields which are radiated into space at the speed of light.

The frequency of such a radiation from a body is determined by the speed of motion of the surface molecules. Their motion is usually random and of many speeds; thus, the radiation consists of many frequencies. The frequency of maximum radiation, however, depends on the the temperature of the body. Very high temperatures (such as those

developed in a rocket motor) produce both visible and infrared radiations; cooler objects (such as a flatiron) produce only infrared.

Since infrared waves are of the same nature as radar and light waves, they have similar characteristics. The differences in the behavior of infrared from that of visible light or radar waves are largely because of the differences in frequency. Infrared is reflected and refracted in a manner similar to light; however, it suffers less absorption when passing through light fog or haze than does visible light. But rain, snow, and water attenuate both to approximately the same extent. Therefore, unlike radar waves, infrared waves require a relatively clear line of sight for reception, though not as clear as visible light.

When infrared is absorbed by an object, the electromagnetic energy increases the speed of motion of the molecules of that object which causes the temperature of the object to increase. Thus, infrared radiation can be detected by its heating effect.

INFRARED DETECTORS

Exhaust gases from internal-combustion propulsion systems radiate, in general, low-frequency infrared waves which can be detected by heat-sensitive devices. Jet propulsion systems, however, require very high combustion temperatures for operation so, in addition to infrared, they emit frequencies in the visible portion of the spectrum which can be detected by photosensitive devices.

Most of the detecting devices used in infrared homing equipment are resistive elements which have a large temperature coefficient of resistance, that is, the change in the specific resistance per degree centigrade is large, as explained in chapter 6 of *Basic Electricity*, NavPers 10086. The most common of these detectors are BOLOMETERS and PHOTOCONDUCTIVE CELLS.

There are two main classes of bolometers—BARRETTERS and THERMISTORS. A BARRETTER, often called a bolometer, con-

sists of a short length of very fine wire, usually platinum, which has a positive temperature coefficient of resistance. (A resistance has a POSITIVE temperature coefficient if its resistance value increases with an increase in temperature, and a NEGATIVE coefficient if its value decreases with an increase in its temperature.) The THERMISTOR is a type of variable resistor made of semiconducting material, such as oxides of manganese, nickel, cobalt, selenium, and copper. It has a negative temperature coefficient of resistance. Thermistors are made in the form of beads, disks, rods, and flakes.

The heat-sensitive materials of thermistors are mixed in various proportions to provide the specific characteristics of resistance versus temperature necessary for target detection. Figure 9–5 shows the change in resistance which can be produced in a typical thermistor material and in a typical barretter. This comparison shows that the thermistor has the larger temperature coefficient of resistance, and therefore is the more sensitive. Thermistors have been developed which are sensitive to temperature changes of ½° F.

PHOTOELECTRIC DETECTORS operate by producing an electrical signal when stimulated by high-frequency infrared or by visible radiation. They are divided into three kinds—photoemissive, photovoltaic, and photoconductive. The PHOTOEMISSIVE type includes vacuum and gas-filled phototubes and photomultipliers. In this type the main effect of the radiation is the production of an electric current in a device having an input impedance of thousands of megohms. These are in common use in sound moving-picture systems, but are not applicable to missile guidance systems. The PHOTOVOLTAIC CELL is used in the familiar photographic light meter; and although it produces small voltages in a low-resistance device, it is generally too sluggish for target-tracking purposes.

The PHOTOCONDUCTIVE CELL uses an element whose resistance varies with the incident radiation and operates in the same manner as a thermistor. Some of the materials used in these cells are thallous-sulfide, lead-sulfide and lead-

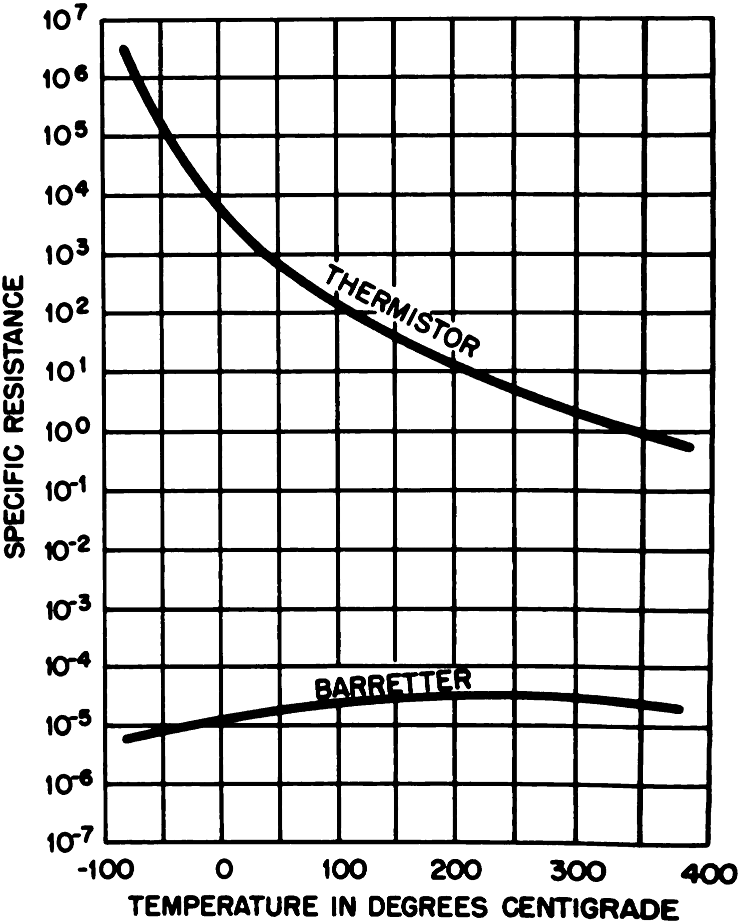


Figure 9–5.—Resistance-temperature comparison of thermistor and barretter.

telluride. The thallous-sulfide cell is the most sensitive to infrared frequencies, but the lead-sulfide cell has the highest speed of response to infra-red and is therefore more adaptable for high-speed target tracking required in missile homing systems.

TARGET DETECTION

All detectors, whether bolometers or photoconductive cells, are used as integral parts of the homing head. They are placed either at the focal point of a parabolic mirror or else are employed in conjunction with lenses which provide a maximum concentration of the infra-red signals at the sensitive surface. As the waves are received from the target, the concentrated radiation is focused on the detector, causing it to change its resistance. A comparatively small d-c voltage is applied to the detector element; and the variations in the resistance caused by the radiation result in corresponding voltage variations.

One method of obtaining directional information is by the use of a rotating parabolic mirror whose axis is offset from the axis of rotation so that its focal point describes a small circle. See figure 9–6. In this arrangement the detector often consists of four elements arranged in a cruciform pattern. The detector is placed so that the focused radiation sweeps across each of the elements in succession, as shown in figure 9–6. In addition to the mirror and detector, two commutators are included in the homing head in this system. One commutator connects one pair of bolometer flakes to the left-right control circuit, while the other connects the remaining pair to the up-down circuit. Each commutator has a rotating arm which is driven by the mirror shaft.

When the target is dead ahead, the rotating target image formed by the mirror describes a circle centered with respect to the bolometer arms. See figure 9–7A. As a result, the bolometer arms divide the circle into four equal 90-degree sectors, as shown in the figure. In this condition, each time the image intersects one of the bolometer arms, the signals developed cannot pass to the control circuits,

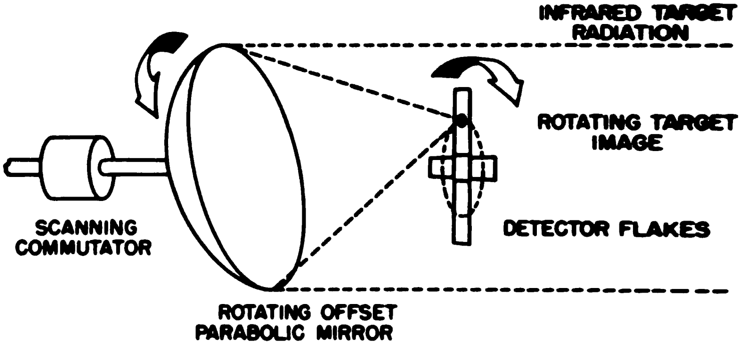


Figure 9–6.—Infrared detection.

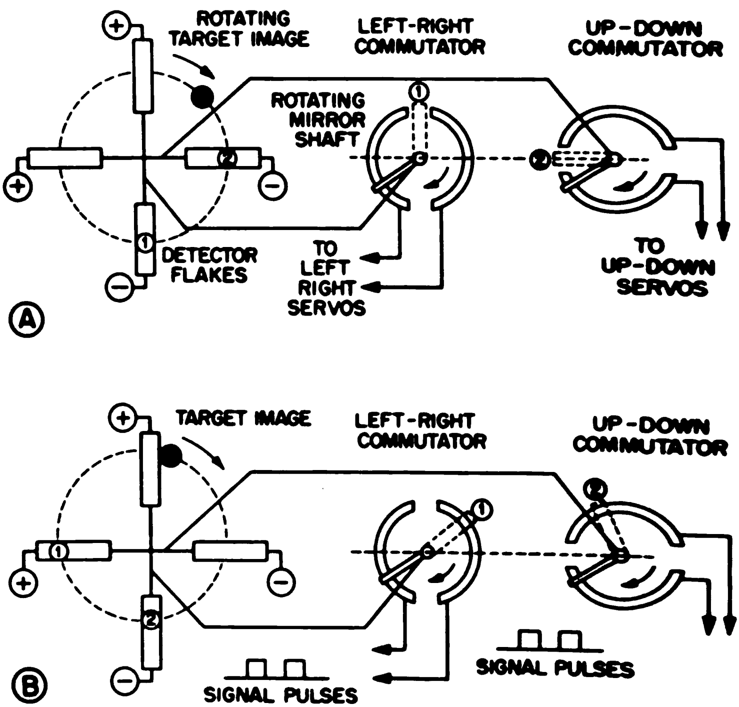


Figure 9–7.—(A) Centered target; (B) target off center.

because at this instant the commutator arms are on one of the insulating segments. Thus no error signals are applied to the control circuits.

In figure 9–7B the condition is shown with an off center target. The circle of the rotating target image is now offset from the center of the bolometer. In this condition the bolometer arms divide the circle into unequal sectors; as a result, the image intersects the flakes when the commutator arms are on the conducting segments. The signals resulting from their intersection will now pass through both commutators to the missile control circuits which cause the proper corrections to be made in the flight path.

As with any system of guidance, the homing system has certain advantages and disadvantages. The principal advantage of this system is that the accuracy increases as the missile approaches the target. The principal disadvantage is its limited range (twenty miles approximately for radar homing and approximately two or three miles for infrared homing). The second disadvantage is that it is adaptable to special targets only. And a third disadvantage is that it requires special launching.

QUIZ

1. Homing guidance is most commonly used for which of the following phases of guidance?
   a. Initial
   b. Midcourse
   c. Terminal

2. Homing guidance in which the missile receiver utilizes radiations from the target which has been illuminated from a source other than one in the missile is referred to as
   a. active homing
   b. semi-active homing
   c. passive homing

3. What term is used to describe the homing system which requires that the missile be continuously pointed at the target?

4. What type of course does a lead homing missile maintain with respect to the target?

5. It is possible to obtain greater range from which one of the following homing guidance systems?
   a. Semi-active
   b. Passive
   c. Active

6. Why is a homing missile inherently more accurate than a beam riding missile?
   a. It is less susceptible to countermeasures.
   b. The homing range converges to zero as the target is approached.
   c. Homing guidance radars can be designed with greater emission power.
   d. Homing systems are not affected by atmospheric conditions.

7. The process by which heat energy is transferred from molecule to molecule by actual contact is called
   a. radiation
   b. convection
   c. conduction

8. Electromagnetic waves which produce heat in any object that absorbs them
   a. are just above those of the color red in the color spectrum
   b. occupy a frequency band which extends from 3000 microns to 760 microns
   c. are called infrared waves
   d. are radiated through space at the speed of sound

9. The frequency of infrared wave radiation from an object is determined by
   a. the size of the object
   b. the temperature of the object
   c. the external shape of the object
   d. the speed of motion of its surface molecules
10. Infrared radiations are attenuated least by which of the following substances?
   a. rain
   b. light fog
   c. snow
   d. water
11. A thermistor is a type of variable resistor which
   a. has a positive temperature coefficient of resistance
   b. consists of a section of fine wire with a positive temperature coefficient of resistance
   c. is made of semiconducting material such as oxides of manganese, nickel, or cobalt
   d. is commonly referred to as a bolometer, although there is no common relationship
12. Which of the following kinds of photoelectric detectors are used in missile guidance systems?
   a. Photoemissive type
   b. Photovoltaic cell
   c. Phototube type
   d. Photoconductive cell
13. Lead-sulfide is the most adaptable photoconductive cell for missile homing systems because it
   a. has a high sensitivity to infrared radiations
   b. has a high speed of response to infrared radiations
   c. is relatively insensitive to infrared radiations not coming from the target
   d. is relatively immune to the effects of deterioration during long storage
14. As a homing missile approaches the target
   a. its accuracy increases
   b. its accuracy decreases
   c. it switches to command guidance
   d. the guidance signal becomes less defined
15. A passive homing system
   a. has unlimited range
   b. requires signal radiations from the missile
   c. is adaptable to special targets only
   d. usually is used for ranges between 25 and 50 miles

CHAPTER 10

COMMAND, INERTIAL, AND PRESET MISSILE GUIDANCE SYSTEMS

The two preceding chapters have covered the beam riding and the homing systems of guidance control. There are other systems which are worthy of note; the first of these is the command guidance system.

A guidance system of the command type is one in which a control station obtains information regarding the relative positions of the target and the missile and sends commands to the missile to direct it toward the target along a desired trajectory. Because of its simplicity and the availability of its components, the command system was the method of guidance most commonly used in the early stages of guided missile development. The bases for any command system are: (1) a means of sighting or tracking the missile from a distant point, (2) a means of interpreting the information obtained and computing the control signal, and (3) a means of transmitting the control information to the missile.

Before continuing this discussion of a command guidance system, let's clarify the difference between a CORRECTION signal and an ERROR signal. A CORRECTION signal is a command that moves the controls a definite amount to correct for an indicated error. An ERROR signal is the detected difference from the required or desired course or altitude or speed. Ordinarily the guidance system first detects the position

error and then develops this signal into a correction signal. After the correction signal is properly formed it is fed into the control system.

Two important links are required for the command system. The first of these is the INFORMATION link. That is, some means of distinguishing the actual position of the missile from the desired position, and of determining the amount of error existing between them, must be available in order that the command operator can develop the proper correction signal. This information link may be electronic or visual. The electronic means may include television or radar. The visual link uses telescopes or the unaided eye.

The second link is the communications or COMMAND link. The commands must be sent in the language of the missile's guidance and control equipment. Command systems are forms of remote control. A manual control unit can operate with only the precision of the human controlling it. To attain increased precision, human control is replaced by an automatic device.

To illustrate, in one instance human control can be replaced by two radars and a computer. One radar tracks the TARGET and obtains its slant range, the elevation angle and the bearing angle. The other radar tracks the MISSILE and observes its slant range, elevation angle and bearing angle. These two sets of data are fed into a computer. Here they are automatically combined and compared. The result of the computer calculation is used to key a command transmitter directing the missile to the target. See figure 10–1.

Another variation of an applied command system is to use a television camera in the missile. This camera transmits a picture of the target to the ground control station. Using subsonic frequencies this picture can be displayed on a small television screen that has cross hairs on it. The control operator sends commands to the missile which keep it in the center of the cross hairs. It is not necessary that the operator see either the missile or the target or track either one in this application.

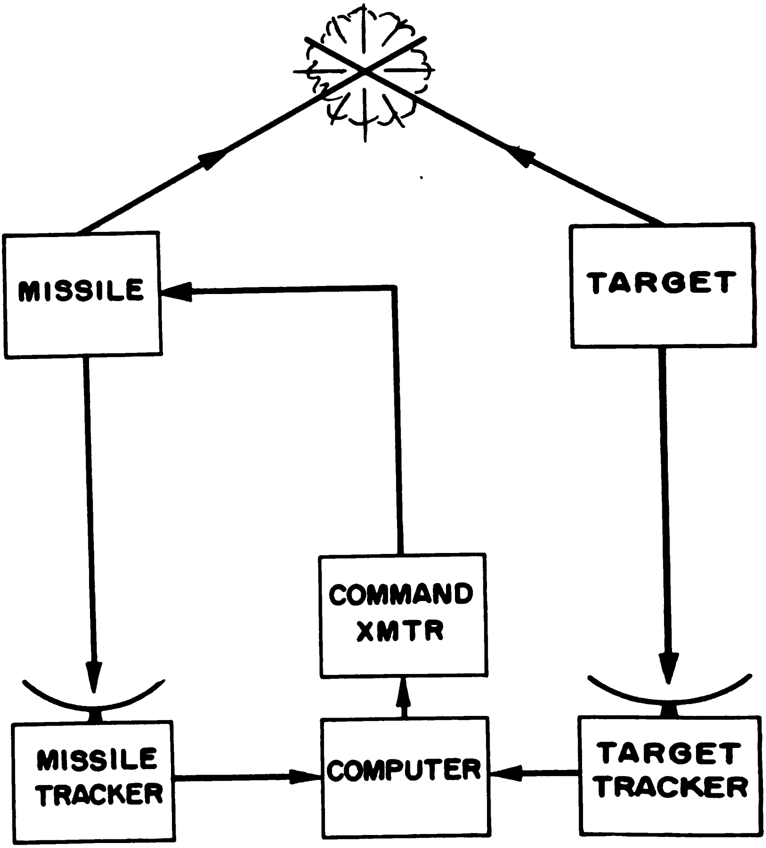


Figure 10–1.—Command system.

Still another variation of the command system is one in which a human operator guides the missile along a line of sight between the target and himself in a manner similar to drone guidance as shown in figure 10–2.

The operation of a command guidance system is illustrated best by starting with the early concepts. The most direct early approach was the use of a multiple transmitter receiver arrangement. The system consisted of using a sep-

arate receiver (one tube) for each command function to be performed by the missile; for example, steer right, steer left, to mention a few. The transmitted carrier signal contained multiple signals and each receiver was tuned to one of these signals. You can see the difficulties in this set up: It was bulky and required a wide r-f band to accommodate all the channels, and because of their number, receivers had to be simple thus resulting in poor sensitivity.

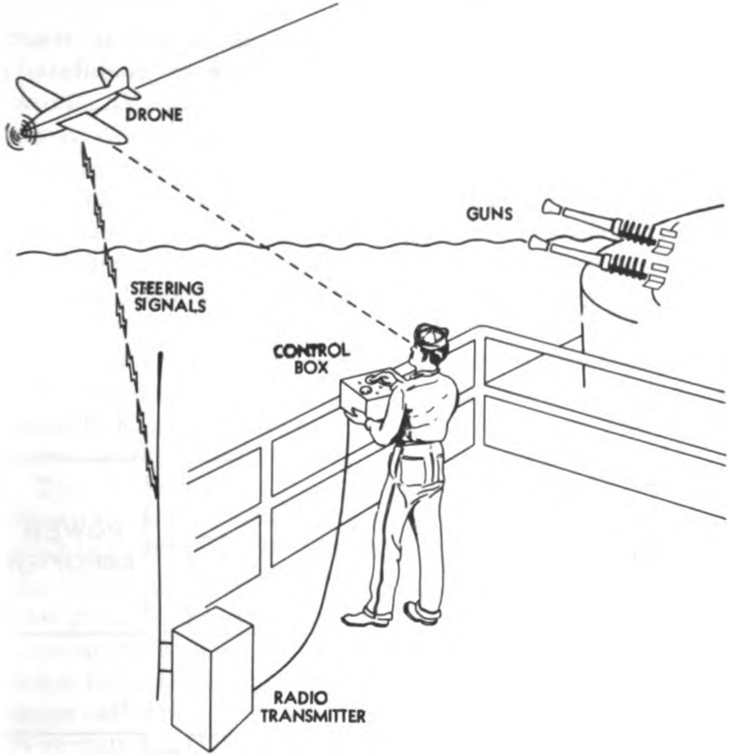


Figure 10–2.—Human command system for drone.

To overcome the disadvantages of the multiple receiver concept, the use of tone channels was the next logical step. This system used a single transmitter modulated with audio frequencies transmitted over one r-f carrier to one receiver.

The carrier was demodulated in the receiver and the outputs, that is the audio frequencies, were applied to tone tuned channels. Whereas the number of operations capable of being handled by the r-f system of multiple receivers was only about four, the audio modulated system was capable of handling twenty possible functions.

Tone systems, however, were troubled by interference from outside sources. Carrier waves having the same tones used by the missile but not associated with the missile system would cause the control functions of the missile to react, which was bad. The use of f-m (frequency modulated) systems helped to eliminate this unfavorable situation. However, some man-made interference of an f-m nature caused difficulty with this system. To overcome this, a system using coded tone pulses was developed. A missile would react only when it was influenced by a series of coded tones simultaneously reaching its receiver. The chance of random or intentional interference which duplicate the coded pulses is negligible.

Figure 10-3 is a block diagram of a command system transmitter such as has just been described. Starting at the input to the system the keyer, we observe the audio sec-

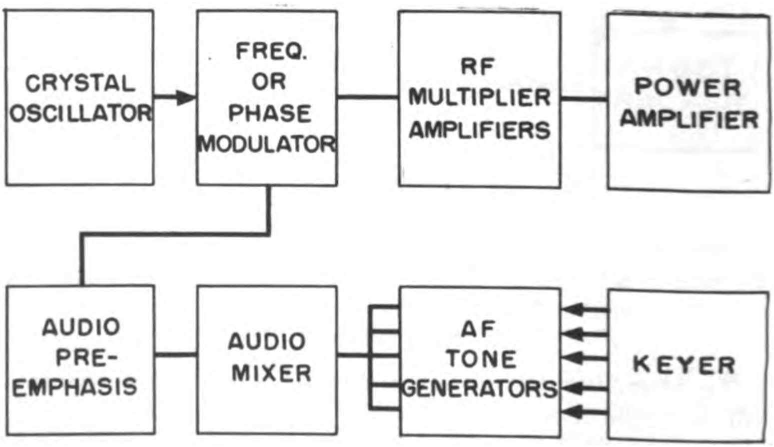


Figure 10-3.—Command transmitter.

tion and the associated keyer. The audio generators, in response to the keyer, generate a tone for each separate order from the computer. For example, one specific tone is "fly right," another "fly left", and so forth for each command for which the computer is wired. The generator will generate this tone only when the keyer actuates the necessary circuitry. The outputs of the audio generator are fed into the mixer. In this "black box" the tones are formed into one composite audio tone and fed to the pre-emphasis circuitry. The purpose of this is to provide a transmitted signal with an optimum signal to noise ratio. Noise consists usually of high frequency components; the pre-emphasis circuitry is necessary only for that range of audio frequencies generated by the audio generator.

The master oscillator for the transmitter is crystal controlled. This provides a very stable and accurate fundamental r-f frequency. The fundamental is modulated by either a phase or frequency modulator. (The principles of phase and frequency modulation are covered in *Basic Electronics*, NavPers 10087.) Upon completion of modulation the fundamental is multiplied and amplified in the same manner as in any other transmitter. The power amplifier supplies the necessary power for transmission to the missile.

The receiver in the missile is the conventional f-m receiver, shown by block diagram in figure 10–4. A refinement which is added here is the carrier fail relay. At the limiter input the limiter grid current is used to operate a carrier fail relay. The grid current is proportional to the strength of the incoming signal; when this signal falls below a predetermined value the relay is actuated. The operation of the relay may cause self destruction of the missile or may cause the missile to remain on its course through a memory circuit. For this reason the carrier wave is transmitted continuously regardless of whether or not there is intelligence superimposed on it.

A second method of issuing command signals is to use command receivers and a tracking radar. To extend the

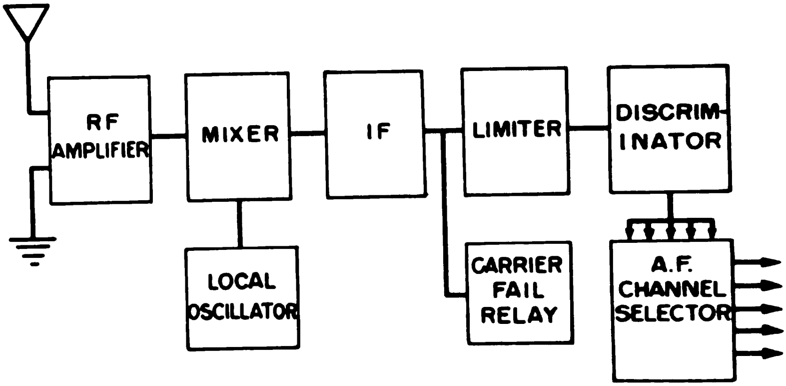


Figure 10—4.—Command receiver.

tracking ranges on small missiles, a beacon is installed in the missile itself. This beacon, when properly triggered by a coded pulse from the radar, returns a stronger signal to the radar receiver than would normally be received from the reflected radar beam. The beacon can be wired to accept command signals, also. In this case an additional set of coded pulses is added to the radar signal, so arranged as to give some intelligence. The beacon accepts these signals and channels them into a unit which decodes them for the intelligence contained. This intelligence is applied to the autopilot.

The foregoing explanations cover the basic concepts of the command system of guidance. It, of course, is not all embracing. You will obtain more specific information on this system from the instruction books which apply to the missiles using this system.

INERTIAL GUIDANCE

An inertial system is a guidance system using a predetermined path where the path of the missile is adjusted after launching by devices wholly within the missile. This system makes use of Newton's Second Law of Motion, and is in-

dependent of any outside information. Guidance is generally accomplished by three double integrating accelerometers that continuously measure the distance traveled by the missile in three mutually perpendicular directions in space. They compare these distances with the desired distances, which are set into a programming device in the missile as functions of range. Two of the accelerometers must respond to missile accelerations only and be insensitive to the earth's gravity pull. Therefore, it is necessary for them to be carried on a platform that is constantly kept perpendicular to the direction of the pull of gravity. This can be accomplished in a moving missile by establishing a space reference system with either gyroscopes or star tracking telescopes. Using this space reference as a base, both the motion of the earth in space and the motion of the missile with respect to the earth can be either compensated for or superimposed mechanically on the space reference. The three mutually perpendicular accelerometers are usually set up with the sensitive axis of one vertical, while the axes of the other two lie in a horizontal plane, one along the flight path and the other at right angles to it. The output of the one along the flight path is distance traveled in range. If the output of the one at right angles to the flight path is kept at zero by maneuvering the missile as required, the missile is kept on the desired path laterally. In some inertial systems the function of the vertical double integrating accelerometer, which keeps the missile at the desired altitude, is performed by a barometric altimeter.

A simple inertial guidance system is shown by block diagram in figure 10–5. Errors in the desired flight path are detected by measuring the lateral (side to side) accelerations and the longitudinal (fore and aft) accelerations during missile flight.

The guidance equipment consists of two main channels—the direction channel and the distance channel. Each contains an accelerometer and a method of computing the output of the accelerometer. This output is a voltage sent to

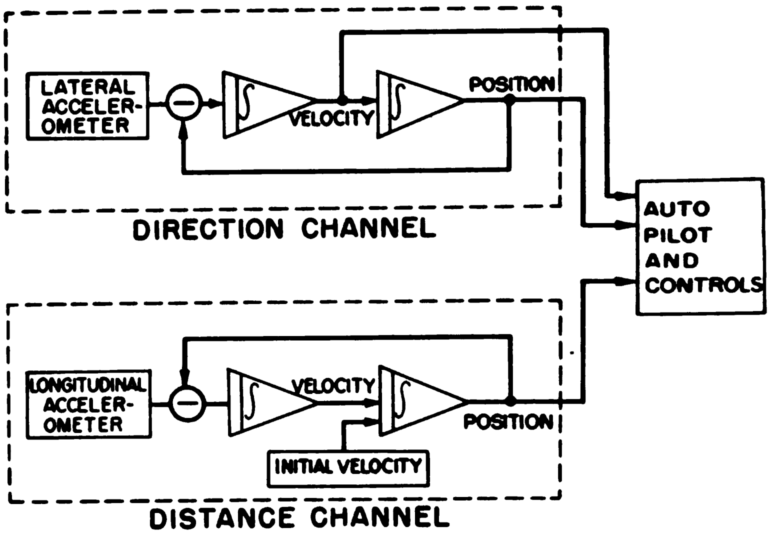


Figure 10–5.—Inertial guidance system.

the computer which consists of two computing units. The first of these determines the velocity.

The velocity output in the form of a voltage is applied to the second computing unit. The second unit determines the distance traveled.

When the missile is on course the output of the direction channel is zero. When the missile drifts off its course the computer output is a voltage representing the distance and direction of drift. The output of the first unit of the computer is the rate of change of direction away from or toward the predetermined course. Both of those signals, the rate of change and the direction and amount of change, are used in the autopilot. The autopilot can detect heading errors but cannot detect off-course conditions, hence the need for two signals to the autopilot.

The method of operation of the distance channel is identical to that of the direction channel. The output of each computer unit represents a different quantity. In the case

of the first unit the output voltage represents the velocity of the missile. The voltage output of the second unit represents the distance the missile has traveled. If the missile system does not operate until a specified velocity is reached account must be taken of the velocity from the time of launch until this time. It is easy to understand that the distance measurement is dependent on the velocity and unless the velocity input is accurate we would have an error in the distance measurement. By injecting the initial velocity into the second computer unit and combining it with the missile velocity from the first unit we are able to determine the changes in velocity of the missile.

If the system does not operate until the missile has reached a specified velocity, then the interim velocity must be accounted for in the distance computation. To allow for this condition the initial velocity is injected into the second computer unit where it is combined with actual velocity. This combination results in a signal which indicates changes in the missile velocity.

The total distance from point of launch to the target must be known. This value is set up as a reference and compared to the distance output of the second computer unit. For example, let the initial distance be 2,000 miles and let it be represented by (—) 2,000 volts. Each mile traveled by the missile would be one volt. By algebraically combining a positive output voltage of the second computer unit with the reference the voltage output would reach zero when the missile was over the target.

Another method is to specify the velocity and use it as a reference. By combining this reference with the output of the first computer unit we feed into the second unit an error above or below the desired condition. When this signal is computed, a distance ahead or behind the desired position on the course is the resultant output. Figure 10–6 shows the block diagram of this method.

Some accelerometer outputs may contain two voltage components. One component is a measure of the missile ac-

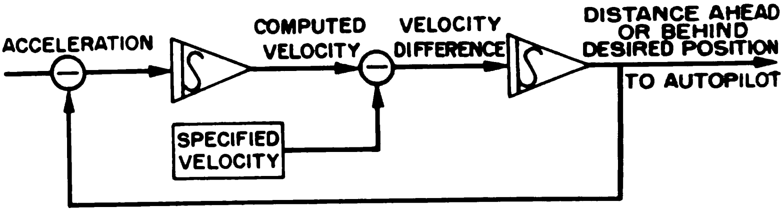


Figure 10–6.—Specified velocity method.

celeration and the other a measure of acceleration due to gravity. It is necessary to separate these components. The acceleration due to gravity is a function of the missile position. If this component is removed from the entire accelerometer output, pure missile acceleration component results. Only the missile acceleration is to be used in the computer to solve for distance traveled. With position data present in the output we can convert this to the proper scale and subtract it from the output of the accelerometer. This explains the presence of feed back circuits in each of the channels of figure 10–5.

The system described above would be sufficient if the missile always flew straight and level. Any variation in pitch or roll would give an erroneous output from the accelerometers in addition to errors caused by the circuitry. A stabilized platform is required to keep these instruments parallel to the earth so that they detect only true acceleration errors. This can be accomplished in a manner similar to the system used for missile stabilization as previously explained in this text.

PRESET GUIDANCE SYSTEMS

A self-contained system of guidance is called a preset system. The intelligence necessary to give the course and termination of the flight is set into the missile prior to its launching. However, the usual definition of preset guidance includes only a simple system that defines heading, altitude, time or length of flight, and programmed turns.

A simple preset system can be broken into two functions. One function is to determine the heading and the other is to determine the distance of flight. This portion of the explanation is therefore divided into two corresponding sections. Various means of accomplishing each of the functions are described.

The most obvious form of heading reference is one which uses the earth's magnetic field. For many years the magnetic compass and its refinements have served as a heading reference. A control arrangement which makes use of a gyrosyn compass is another example of a preset reference for heading. The yaw gyro of a control system is another typical example of a preset reference. If a gyro is not capable of being processed from an external source while in flight, the heading set in prior to launching controls the path of the missile.

The length of flight can also be taken care of in a simple fashion. The distance a missile has flown can be determined by the use of an air log or by computing the average velocity of flight for the time the missile has flown. An air log consists of a small propeller of known pitch which turns a Veeder-root counter. Through a precision gear box connecting the propeller and counter it can be made to show miles, feet, kilometers, or any arbitrary measure of distance.

Air pressure developed by missile movement can also be used to make an airspeed meter give an indication of velocity. By integrating (summing the average) airspeed over the time of the flight, a continuous check of the distance flown is obtained. This method has the same accuracy as the air log, and the only reason for choosing one or the other is the availability of components.

The latter method could make use of standard equipment but would usually require an electronic installation. The air log equipment would be all mechanical, merely energizing a switch or relay at the dump point. (The dump point is the point in space at which the missile is programmed into the target.)

Another possible method of determining distance flown uses an airspeed reference set into the controls section and a clock for time elapsed in flight. This method is the most inaccurate. Besides being subject to all the errors that the other systems are subject to, this system's accuracy is affected by the capability of the missile in maintaining a constant (reference) airspeed.

The Launcher Bias

The simplest form of a preset system, as used in almost all missiles, is known as the "launch bias." Because of the tremendous acceleration occurring at the launching of a missile, the mechanical and electromechanical components do not function properly at take-off. To take the missile through this initial stage of its flight, fixed control and throttle settings are made before the launching takes place. These control settings are calculated for a stable climb-out during the initial acceleration, until the regular guidance and control systems can take over.

Altitude Reference

In addition to heading and distance, there is a third aspect of missile flight which must be considered. This is an altitude reference. An altitude transducer is used to control the height of the missile flight. An altitude transducer is an altimeter with an electric output. The simplicity and accuracy of the altitude transducer has resulted in its remaining the primary altitude control or reference in even the latest guidance systems.

Summary of Preset Systems

The preset system was the earliest of the methods of guidance, and in some form will undoubtedly be the longest in use. The "preset" settings for launching missiles are always necessary whether they are made manually, as with the surface-to surface missile, or automatically, as set in by gunsight computers in air-launched missiles; whether they

last for many minutes as in the World War II missiles, or mere seconds as in present systems.

These past three chapters have introduced you to the systems of guidance which are most prevalent in the present day missiles. They are important to you particularly as these systems pertain for the most part to surface launched missiles. To summarize the information you might classify each system used in regard to range of performance as follows:

Beam rider—short range
Homing—short range
Command—short range
Preset—short range
Inertial—long range

Each of these has its own advantages and disadvantages. Each may be combined, one with another. The particular tactical situation for which the missile is designed will determine which type or combination of types of guidance systems will be used for the missile. Your missile manuals will detail this for the missiles you will work with.

QUIZ

1. A command system of guidance does NOT require which of the following?
   a. Means of sighting or tracking the missile from a distant point
   b. A means of interpreting the information obtained and computing the control signal
   c. A means within the missile to measure continuously the distance it has traveled in three mutually perpendicular directions in space
   d. A means of transmitting the control information to the missile

2. A correction signal in a command guidance system is
   a. a command which actuates missile controls a definite amount to correct for an indicated error
   b. the detached difference from the required or desired course, altitude, or speed
   c. a signal indicating the amount and the direction that the missile has drifted off course
   d. a signal indicating the rate and the relative direction that the missile has drifted off course

3. What are the two essential links of a command guidance system called?

4. Which of the following are disadvantages of the multiple transmitter receiver arrangement of command guidance?
   a. It is bulky.
   b. It requires a wide r-f band to accommodate all channels.
   c. Its receivers are simple and thus have poor sensitivity.
   d. All of the above.

5. To eliminate guidance responses to outside interference some command systems use
   a. coded pulses
   b. simple one tube missile receivers
   c. superheterodyne missile receivers
   d. decoupling filters

6. What is the purpose of the pre-emphasis circuitry in a command transmitter which uses tone channels?
   a. To initiate generation of tones for each command
   b. To form all tones into one composite audio tone for emphasis
   c. To key the correct tone channels in audio generators
   d. To provide a transmitted signal with an optimum signal to noise ratio

7. The receiver in a missile using a command guidance system with tone channels is which of the following types?
   a. A–M receiver
   b. F–M receiver
   c. Crystal receiver
   d. Tuned radio frequency receiver

8. In the inertial guidance system
   a. the path of the missile is adjusted after launching by devices wholly within the missile
   b. use is made of the principle that a body at rest remains at rest, and a body in motion continues in motion unless it is acted on by an outside force
   c. use is made of the principle that for every action, there is an equal and opposite reaction
   d. the path of the missile is adjusted by reference to inert terrestial objects

9. In the inertial guidance systems the output of the double integrating accelerometer whose sensitive axis is along the flight path is
   a. control signals to maintain altitude
   b. maintained at zero by changing the missile heading
   c. distance traveled in range
   d. missile velocity along the flight path

10. The function of the accelerometer which is mounted with its sensitive axis ———————— is sometimes performed by a barometric altimeter.
    a. along the flight path in a horizontal plane
    b. at right angles to the flight path in a horizontal plane
    c. vertical

11. What does the first computer in the distance channel of the inertial system measure?
    a. Velocity
    b. Distance
    c. Acceleration
    d. Gravity

12. What does the second computer in the distance channel of an inertial system measure?
    a. Velocity
    b. Distance
    c. Acceleration
    d. Gravity

13. The fundamental functions of a simple, preset guidance system are
   a. to determine the altitude and direction of the flight
   b. to determine the velocity and distance of the flight
   c. to determine the velocity and dump point of the flight
   d. to determine the heading and distance of the flight

14. Which of the following methods is the least accurate for determining the distance of flight for a preset missile?
   a. Integrating measured airspeed over the time of flight
   b. An airspeed reference set into the controls section and a timer to measure elapsed time in flight
   c. A mechanical air log

15. The dump point in a missile flight is the point in space where
   a. the missile is directed into the target
   b. the propulsion plant is secured
   c. excess fuel is released
   d. the warhead is released from the missile

CHAPTER 11

INTRODUCTION TO MISSILE CONTROL SYSTEMS

In chapter 4 we discussed components of the guided missile and you became acquainted with some of the terms peculiar to the control and guidance components. This and the following chapter will expand upon the subject of control systems.

A control system is one which maintains the selected missile heading and attitude. In effect it provides a smooth stable flight. A guidance system determines the required direction of flight to direct a missile to a specific location. In other words, the guidance system determines what should happen to make the missile hit its target; the control system makes this happen. The point at which the guidance system ends and the control system begins is, in most cases, difficult to distinguish. The two systems are dependent one upon the other to complete successfully the desired mission. It is possible to operate a specific control system with more than one type of guidance system or one guidance system may operate more than one type control system. Because of this a division between the two systems can be made.

Because stable flight is maintained by missile control surfaces, a logical method of classifying control systems is by the methods used to move these surfaces. This method of classification gives the following types: pneumatic, hydraulic and electric control systems. Using this, let us consider the various control systems.

Missile control systems are dominated by servomechanisms. There are four types of servomechanism systems. The OPEN-LOOP system is one in which the control operation is independent of the result. The CLOSED-LOOP system is one in which the control operation is a function of the result. This means that the result of the servomechanism's action is measured at the load and the measurement is followed by a corresponding further action of the control. The DISCONTINUOUS system is a third type in which control is exercised on the basis that the error is a function only of the direction of the difference between input and output. In addition, the error correction is not proportional to the amount of the difference between input and output. This system develops its full driving TORQUE (turning force) whenever it is in receipt of an error, regardless of its size. This system is referred to as the "delay on-off" or "bang-bang" system. The fourth system is called the CONTINUOUS system. It will act continuously provided the input signal is greater than some predetermined level referred to as the THRESHOLD. The error correction in this system is proportional in both direction and size to the difference between input and output. The controller, therefore, drives the output with a torque proportional to both the direction and amount of the error.

The entire purpose of a servo is to cause the output of a system to follow or do what the input commands. A simple illustration is shown in figure 11–1. The large heavy disc is to be positioned in such a way that one turn of the crank (input) results in one revolution of the disc (output). By gears and a motor it is possible to amplify a small input and cause it to move a heavy load. With such an open-loop continuous system, however, there is no assurance that, after the load has been rotated, the output angular displacement (θ_o) will be equal to the input angular displacement (θ_i).

To improve this system it is modified by installing a FEEDBACK loop. This is a circuit which detects and sends in-

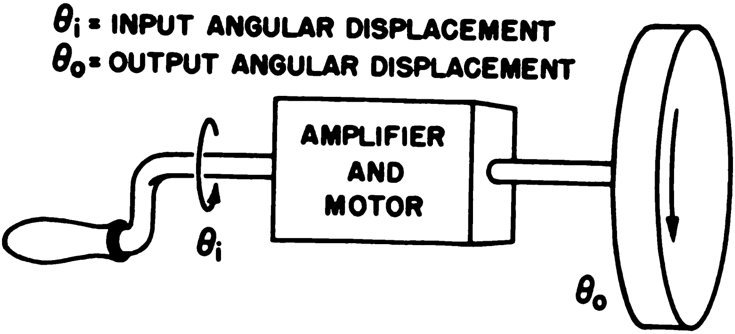


Figure 11–1.—Open-loop continuous servo system.

formation regarding the amount of output rotation back to an error detecting device, where this output is compared with the original input. If there is a difference between the input and the output positions (angular displacement), an error signal equal to their difference continues to keep the system in motion until finally the output equals the input ($\theta_i = \theta_o$). This is called a position or proportional control servo. The purpose of the PROPORTIONAL CONTROL servo is to drive the output load, which may be remotely located, in such a manner that the load position always corresponds to that of the input member of the system. Thus we have a CLOSED-LOOP, continuous system, shown schematically in figure 11–2. The closed-loop system is the one with which

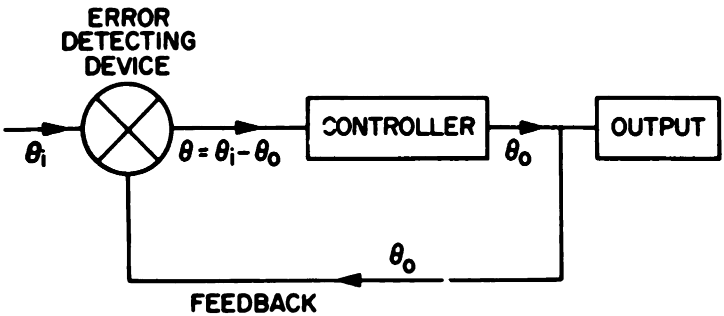


Figure 11–2.—Closed loop continuous servo system.

we shall be most concerned in the missile field; the discussion from here on will be confined to this type.

Closed-loop System

There are five basic components required for the simplest closed-loop system. In the order of appearance in the system they are the INPUT, the ERROR DETECTING DEVICE, the CONTROLLER, the OUTPUT and the FEEDBACK. The input to a servo system is the signal or command that changes the working level of the system by changing the angular position or velocity of the output to correspond to the input. An example of this may be the signals sent by an autopilot of a missile

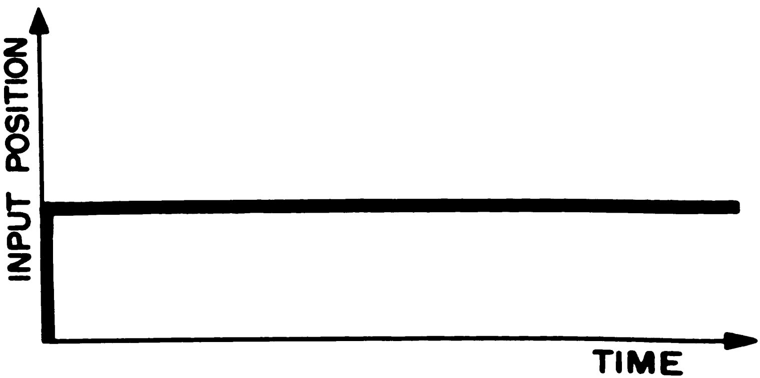


Figure 11–3.—Position vs time plot—position input.

to the servo system. This autopilot detects deviations of the missile from its proper attitude and sends signals proportional to the size and type of attitude errors to the servo system, which activates the control surfaces to correct the missile's attitude. Because a variety of forces act on the missile, the missile's attitude requires constant supervision and corrections of all types. This requires a variety of input signals to the servo system associated with the control surfaces. The known inputs to a servo system may be classified as CONSTANT POSITION, CONSTANT VELOCITY or SINUSOIDAL.

For a rotary servo system a CONSTANT POSITION or step position input is one in which the input member or shaft is rotated a certain amount from some reference position, beginning at zero time, and then stopped. The input member then remains in that position until a new input command is received. A position versus time plot of this action is shown in figure 11–3.

A CONSTANT VELOCITY input function is one in which the input member is motionless until some instant when it begins to move continuously at a constant angular velocity so that the input angle increases directly with time. This is shown in figure 11–4.

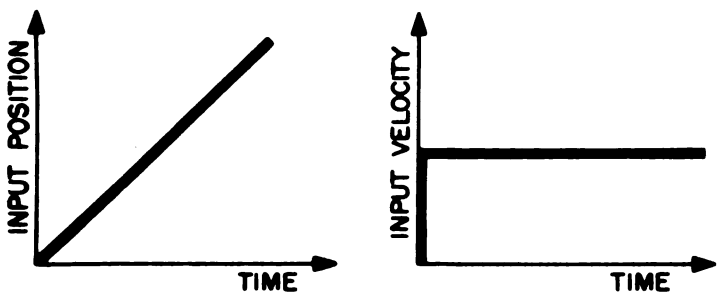


Figure 11–4.—Velocity vs time plot—constant velocity input.

A SINUSOIDAL INPUT is one in which the input member is rotated a given amount in one direction and then the rotation is reversed. Oscillation takes place at some constant angular velocity and with some constant amplitude. This motion is diagrammed in figure 11–5 as a plot of amplitude of oscillation versus time.

The inputs which have been described are those used for the theoretical analysis of servo systems and are not necessarily those which a missile will experience, specifically, in actual flight. A missile's inputs may be random sinusoidal inputs or a combination of all three types.

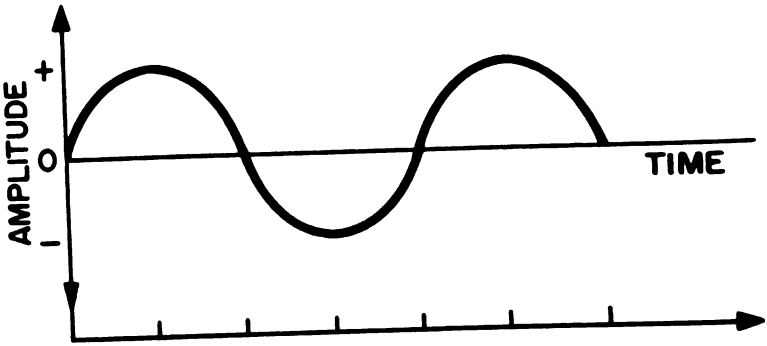


Figure 11–5.—Amplitude vs time plot—constant velocity input.

An ERROR-DETECTING device is a mechanical or electro-mechanical differential which gives an indication of the size and direction of the error or of the difference between the instantaneous positions of the input and the output. This error may be expressed as a difference signal that is the signal upon which the servo system actually operates. Without the difference signal the controller, which develops the torque to drive the output, could not operate. In the simple servo, without a closed loop, the system is either at rest or the output equals the input and there is no further need for a driving torque. Error signals may be divided into two types: the TRANSIENT, and the STEADY-STATE errors.

TRANSIENT ERRORS are caused by the inability of the output, because of the inertia of the load, the sudden variations of the input. The error is transient because, after the inertia of the load has been overcome and it begins to move, the error is reduced. It is possible, in this case, that the load will overshoot the input in an attempt to catch up and follow the input, because of the inertia of the output. The error-detecting device detects this transient error between input and output positions when overshoot has occurred, as well as when the input signal is first given, and causes the output to reverse its direction of motion. After reversal, the output may again overshoot the input. The resulting oscilla-

tion of output about the input position is the usual form of transient error and is illustrated in figure 11–6 for a step position input. The transient error in the illustration is the instantaneous difference between input and output positions, which is varying with time. The elimination of this error is important; missile performance considerations usually require that the transient error be corrected in a minimum of time. In other words, we want the output to follow the movement of the input rapidly, and such is not the case as long as the output is oscillating about its desired position.

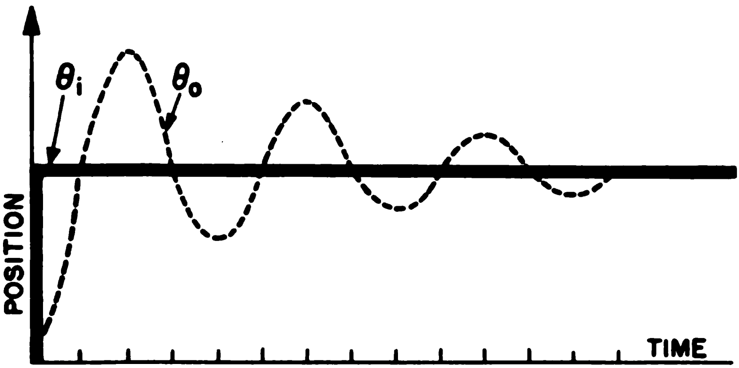


Figure 11–6.—Transient error plot.

STEADY-STATE is that stable operating condition of a system in which sufficient time has elapsed since initiation of motion that all transient errors have died out. In other words, if the input is set in motion with a constant velocity, then after the output has accelerated and settled down to the same angular velocity as the input, steady-state conditions exist. Then the amount by which the output position lags behind that of the input is called the steady-state error. The steady-state error varies in value with the type of input to the system.

This is shown graphically in figure 11–7 where input and output positions are plotted for the various types of inputs.

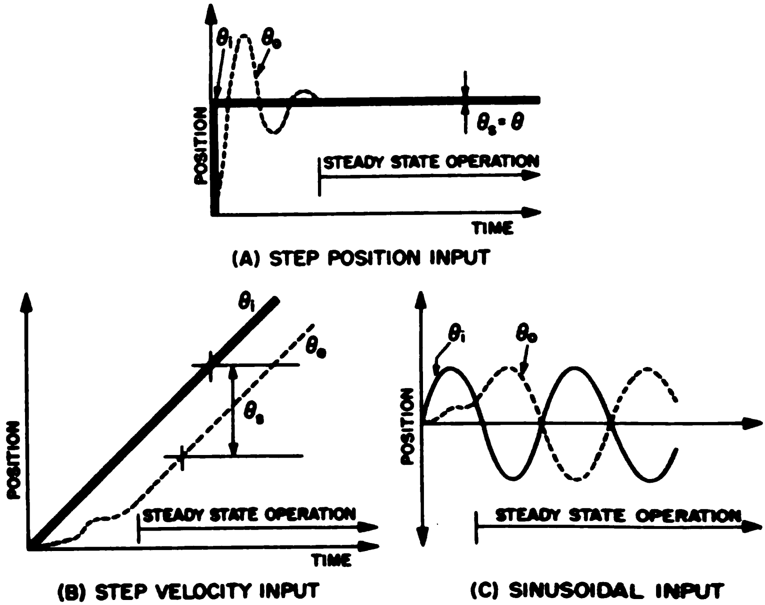


Figure 11–7.—Steady state errors.

For the STEP POSITION input (fig. 11–7A), the output may oscillate initially, causing a transient error, but it should remain in motion until eventually its position corresponds to that of the input, as shown. Hence the steady-state error for step-position in parts is equal to zero.

When the system is subjected to a STEP VELOCITY input see figure 11–7B, the output will likely go through a transient period of oscillation. But when the final output is traveling at input velocity, the actual position of the output at any instant is lagging behind the input by a constant amount, that amount being steady-state error.

For a *sinusoidal* input (fig. 11–7C) the steady-state error appears as a phase lag between output and input. This error is caused by friction or damping in the system, which acts to retard the motion of the output. Hence, it is necessary for the controller to produce a continuous driving

torque to work against this retarding force in order to keep the output moving at input speed. The accelerating torque of the controller does not eliminate this undesirable retarding but merely opposes it. The constant lagging of the output behind the input stays with the system as long as the same input velocity is maintained. Increasing or decreasing the input velocity in this case varies the magnitude of the steady-state error since it is proportional to velocity.

A CONTROLLER is a power device that is controlled by the small error signal received from the error detector. Since the signal detected is usually so small, it must be amplified before it will drive the actuators which are connected to the control surfaces. The controller usually consists of an amplifier and the necessary motors, solenoids, and other equipment used to drive or position the output. The fundamentals of servo motors are covered in *Basic Electricity*, NavPers 10086, and the fundamentals of amplifiers are covered in *Basic Electronics*, NavPers 10087.

The way in which the controllers are incorporated in specific missiles is explained in the manuals for each missile. A general description of an electric control system controller will be given later in this chapter.

FEEDBACK has been defined earlier in this chapter. Feedback is accomplished with potentiometers, synchros, gyros and similar devices in combination with electrical or other circuits.

Figure 11–2 shows the methods in which all of these components are put together to make up the simple closed-loop continuous servo system.

Loops

The term "loop" appeared in the foregoing discussion in connection with feedback. In a true servo system the output or some function of the output is fed back to the input for comparison. The system which we have considered previously has been a relatively simple, single-loop servo in which only the output position was fed back for comparison. Let

us now examine systems in which other functions or forms of the output are fed back, necessitating additional loops. The multiple-loop system is a complete servo system which operates on other functions of the system in addition to the final output and initial input.

The need for additional loops in such a system becomes clear when we consider the following questions:

How is the input affected by the change in the output?

How does the response of the missile to commands received affect the need for, or the form of, further commands?

These considerations require that we examine the overall missile control system. This involves getting the response of the missile. To get this response we must add an external feedback. The function of this external feedback is to return the missile's aerodynamic response to a signal to the error detecting device supplying the input. The response of the missile is either what determines the need for the continuation of the original input or for a new input. For example, a signal is received which requires the missile to be deflected 15° from base course. This is the original input. As the missile turns to the new course the signal will be applied for a period of time. The rate at which the missile turns determines how long the signal must be applied. This is the response which must be known. If the response is rapid and the missile overshoots the new course, then a new input will be required to correct for this overshoot. Another requirement which makes use of the multiple-loop system necessary is rapid detection of response. Certain actions of the output may be more rapidly determined by additional feedback loops than they could be by use of the normal output feedback loop.

Heretofore we have been discussing the simple servo system where only the physical movement of the output as a result of input was the consideration. The type of feedback referred to in the simple system was internal feedback. This internal feedback discussed was actually a physical connection in the missile through which an electrical potential

proportional to the output was returned to the input. On the other hand, external feedback is, as the name implies, outside of the missile with no direct connection.

External Feedback

An example is the best method of illustrating the external feedback idea. For this explanation we shall use an arbitrary roll control system. Refer to figure 11–8.

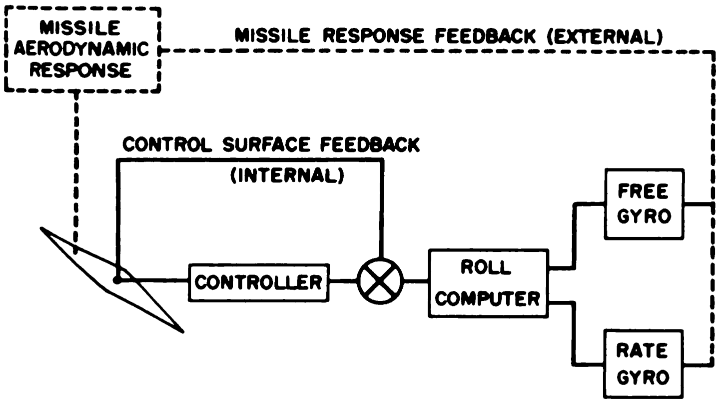


Figure 11–8.—Roll control network.

The input to this system, to correct for any roll which may have taken place, comes from the roll computer. The output of the controller, a signal requiring the necessary wing movement to cause the missile to roll an appropriate amount in the opposite direction to compensate for the error, is compared with existing amount of control surface deflection. The difference between the input signal and the position feedback signal drives the controller which in turn drives the servo motors or actuates the servo valves and causes the control surfaces to move. Assume that an input signal is generated and the missile starts to correct itself. The computer must be fed this response in order to stop the correction by neutralizing the control surfaces.

This is done by external feedbacks. The gyros in the missile detect the response to the error signal and convert the missile motion into an electrical signal which is sent to the computer. The block showing aerodynamic response in figure 11–8 is simply a symbol; there is no actual physical connection between the control surfaces and the gyros. The computer receives information that the missile has returned to its zero-roll position and hence "knows" the control surfaces should be neutralized. The process is a continuing one; the roll error decreases steadily as the missile returns to normal and the deflection of the control surfaces is therefore reduced by the computer. Note that two gyros are used. If the free gyro (which detects a signal proportional to the actual amount of roll of the missile) were used alone, the angular momentum of the missile as it returns to its zero-roll position would cause the missile to overshoot this position, resulting in a roll error in the opposite direction. This oscillation would continue as the roll system, working on a free-gyro signal only, reversed itself with each overshoot. Thus we would have an underdamped system with the undesirable feature of missile roll oscillation whenever corrections for a roll error were attempted. The rate gyro helps to overcome this situation by a form of error-rate damping. The rate gyro was briefly mentioned in chapter 4 of this text. Figure 11–9 will refresh your memory concerning the principal parts and the mechanics of this assembly. Notice that a pair of springs has been attached to the lever arm on the output axis in this diagram of the gyro and that these springs restrain the free precession of the gyro. They do not stop the precession but merely restrain it. As the gyro precesses, it exerts a force proportional to the momentum of the spinning wheel and the applied force.

For example, suppose the gyro case is rotated at a speed which is proportional to applying a horizontal force of 2 pounds at F, as shown in the figure. Obviously, the gyro will precess; and as it does, it will cause the crossarm to

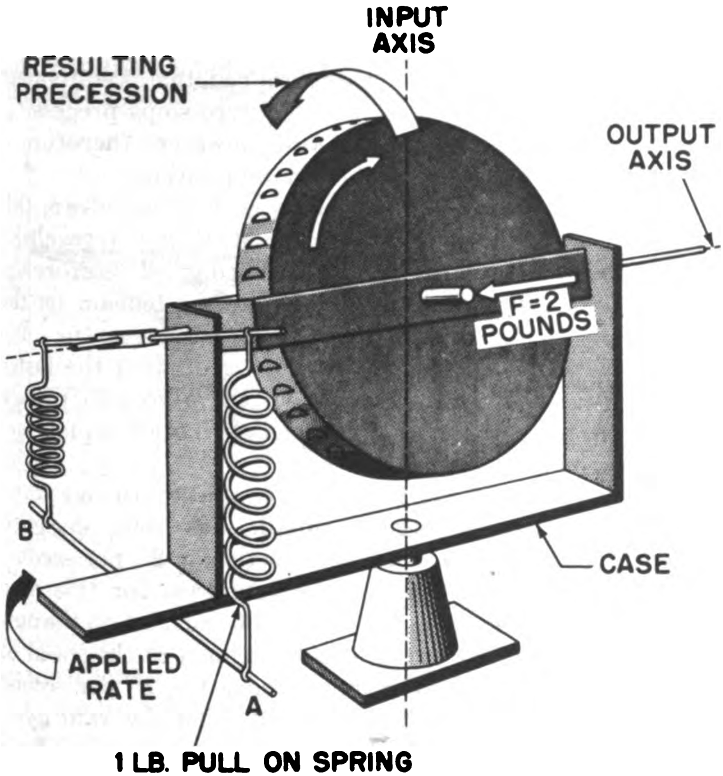


Figure 11–9.—Simplified rate gyro.

pull up on the spring A with a certain force—say one pound. This of course varies with the length of the crossarm.

If you continue to turn the gyro case at this rate, the precession of the gyro will continually exert a pull on the spring. More precisely, the gyro will precess until 1-pound pull of the crossarm is exactly counterbalanced by the tension of the spring.

As turning continues at the same rate, the gyro will continually try to precess further, but since its pull is balanced by the tension of the spring, it will remain in a fixed position as shown in the figure. That is, it will remain in the

precessed position as long as you continue to rotate the case at the same constant speed.

When the rotation of the case is stopped, that is equivalent to removing the force at F, and the gyro stops precessing. The spring is still exerting a pull, however; therefore it pulls the crossarm back to the horizontal position.

Should the case be rotated twice as fast as before, this would be equal to a 4-pound force at F and a resulting 2-pound pull by the crossarm on the spring. Therefore the gyro would precess twice as far before the tension on the restraining spring equaled the pull on the crossarm. We might summarize this explanation by saying that the faster the gyro case is rotated, the farther the gyro will precess before the pulls of the crossarm and spring are equal, and the gyro comes to rest.

The operation of the rate gyro is applied to our servo systems. Suppose a certain missile has been designed wherein the maximum speed of reaction is 2° per second. This is an arbitrary figure. The rate gyro for this missile would be designed so that a force of restraint on the output axis of the gyro would be proportional to the speed of reaction. Any speed of reaction above the 2° per second maximum would result in an output from the rate gyro. For instance, if the missile were to receive a command for a change of heading of 10° and the missile started to correct for this change in excess of the rate of 2°/sec, then the rate gyro would sense this excess and modify the intelligence sent to the computer in such a manner as to decrease the rate of heading change.

The algebraic sum of the signals from the rate gyro and the free gyro is the intelligence sent to the computer. These signals are proportional to the amount roll and also the rate of change of this amount. A positive direction of roll is established by convention. When the roll and roll rate have the same sign (positive roll and positive rate or negative roll and negative rate), the computer acts on the sum of the two. When the roll and roll rate are of opposite

sign (positive roll and negative rate or negative roll and positive rate) the computer acts on the difference. The result of the computer acting upon these two signals is a damping action. Figure 11–10 is a graph showing the roll

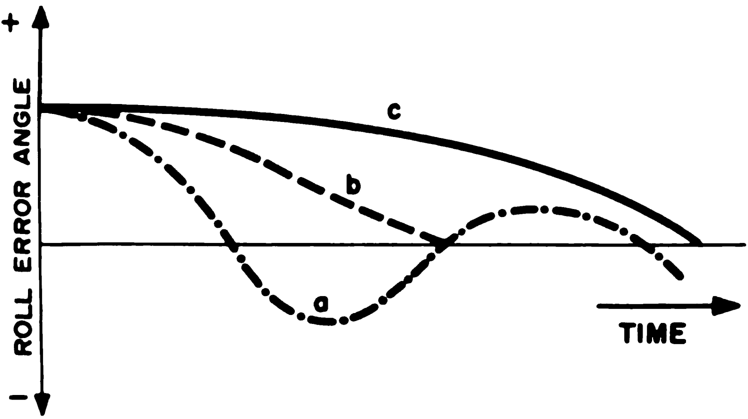


Figure 11–10.—Roll error angle vs time.

error angle vs time. Curve (a) is the result of an UNDERDAMPED condition. When the missile is in this condition it continually oscillates about the desired output. Curve (c) is the result of an OVERDAMPED condition. A missile in this condition acts very slowly to achieve the desired output. Curve (b) is the result of CRITICAL damping. Critical damping is a condition wherein the missile achieves the desired output in the shortest possible time after disturbance.

PATH CONTROL SYSTEM

We shall now extend this coverage of the multiple-loop servo system by discussing a complete theoretical missile path control system. Further, the assumption will be made that this is a command guidance system and that the missile will maneuver on pitch and yaw acceleration commands. This is somewhat different from the position-control type servos in which the output merely attempts to follow the

position of the input. The same basic principles are involved, however, in the acceleration control servos since the output attempts to develop the acceleration demanded by the input to the system. This type of system simplifies maneuvering a missile to a point in space or along a desired trajectory. Many path control systems employ such acceleration commands.

Figure 11–11 is a block diagram of a multiple closed-loop servo system. In order to simplify the explanation to follow, we shall use the symbols below.

E_a = accelerometer generated voltage.
E_s = voltage generated by shaping networks.
E_i = voltage introduced into the system.
E_r = voltage generated by rate gyro.
E_d = voltage generated by control surface displacement.

Combinations of these symbols such as E_{as} mean that a voltage generated by the accelerometer has passed through the shaping network.

The initial input to the system is an acceleration command which we will assume is in the pitch plane. By suitable circuits this command is converted to an electrical signal and applied to the system as a voltage (E_i). As a result of external feedback the accelerometer generates the

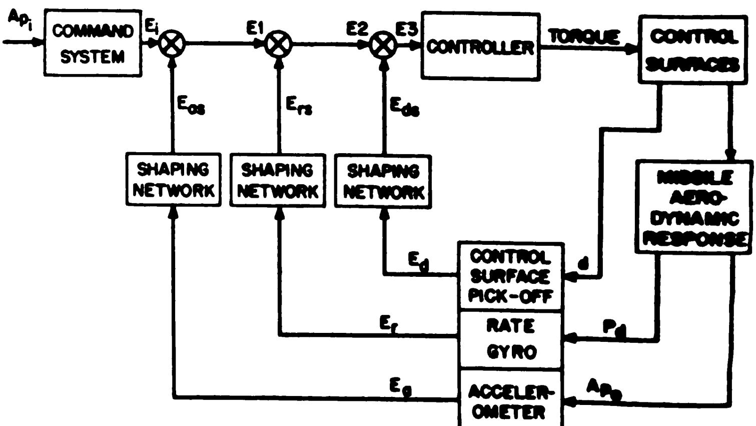


Figure 11–11.—Multiple-loop servo system.

voltage E_a and this voltage is acted upon by the shaping network to give the voltage E_{as}. The shaped output is compared with the input E_i. The shaped acceleration voltage is a function of the pitch acceleration which the missile is undergoing at any instant (possibly zero). Let us call the difference between the voltage applied to the system as a result of the command (E_i) and the shaped acceleration voltage (E_{as}) by the symbol $E1$.

The rate gyro output is the result of the effect of missile movement on the rate gyro which causes it to supply an output potential (E_r) proportional to the rate of change of missile heading. The potential (E_r) is acted upon by the shaping network to produce the shaped rate gyro output (E_{rs}). This voltage (E_{rs}) is compared with $E1$ which results in the voltage represented by the symbol $E2$.

The voltage E_d is the result of a potential proportional to the actual control surface displacement. This potential (E_d) is acted upon by the shaping network to produce the shaped displacement voltage (E_{ds}). This voltage (E_{ds}) is compared with $E2$ which results in the voltage represented by the symbol $E3$.

The voltage $E3$ is applied to the controller which exerts a torque on the control surfaces proportional to the size of the signal $E3$. The result is a change of heading in the pitch plane to achieve the desired acceleration required.

The purpose of the shaping networks, which have been mentioned frequently in this discussion, is to weigh the various functions fed into them in order to vary the net effects of these different functions, E_a, E_r and E_s, during the time sequence following the acceleration input. This is done because of the requirement that the missile respond as rapidly as possible, thereby making it highly maneuverable. Because of this the missile servo system needs rapid feedback to determine how the missile is responding to acceleration commands. There will always be time delays in the system. A control surface movement will be experienced first and a very short time afterward a rate of change of heading is experienced before any acceleration of the missile can be

determined. The system uses control-surface position and change of heading feedback to begin nulling the input acceleration voltage. This is done in anticipation of an output acceleration and before the output acceleration has actually been detected. By the time the missile is accelerating as ordered by the input, the net voltage E_3 decreases in time sequence as the system begins to detect the missile's acceleration. Finally the output acceleration voltage E_a, sent through the shaping network, is the only signal being compared with the input (E_1) voltage.

The same system may be used to cause yaw accelerations of the missile. This must be done so that the missile control system can differentiate pitch acceleration commands from yaw acceleration commands and respond accordingly. Note that nothing has been said about the source of these input acceleration commands. This, of course, requires an additional system to track the missile in flight, determine its position relative to the target, and compute the commands which the missile must receive in order to maneuver to the target.

Accelerometer

The accelerometer referred to in the multiple-loop system is a device which measures the acceleration of the missile. Remember that acceleration is the time rate of change of velocity. Acceleration is a vector quantity and can change in value by either a change in velocity or by change in direction in which the velocity is acting. It is in the measurement of one or both of these factors that we employ the accelerometer.

This device is made up of three basic parts which are: the spring, a weight or suspended mass, and the damping system. These three parts are common to all accelerometers. The basic parts are mounted within a frame which is in turn mounted to the missile proper. The spring provides the elasticity of the system and offers a restraining force proportional to the displacement of the weight and opposed in direction to the weight movement. The weight is suspended

in the frame from the spring and, because of its inertia, opposes any change in its state of rest or uniform motion. The greater the mass weight the greater the force required to produce a given change—as stated in Newton's second law of motion. Then there is the damping system within or sometimes a part of the frame which may be a viscous fluid or an electro magnetic force. (A viscous fluid is one which does not flow readily.) Thus the viscous fluid or the e-m

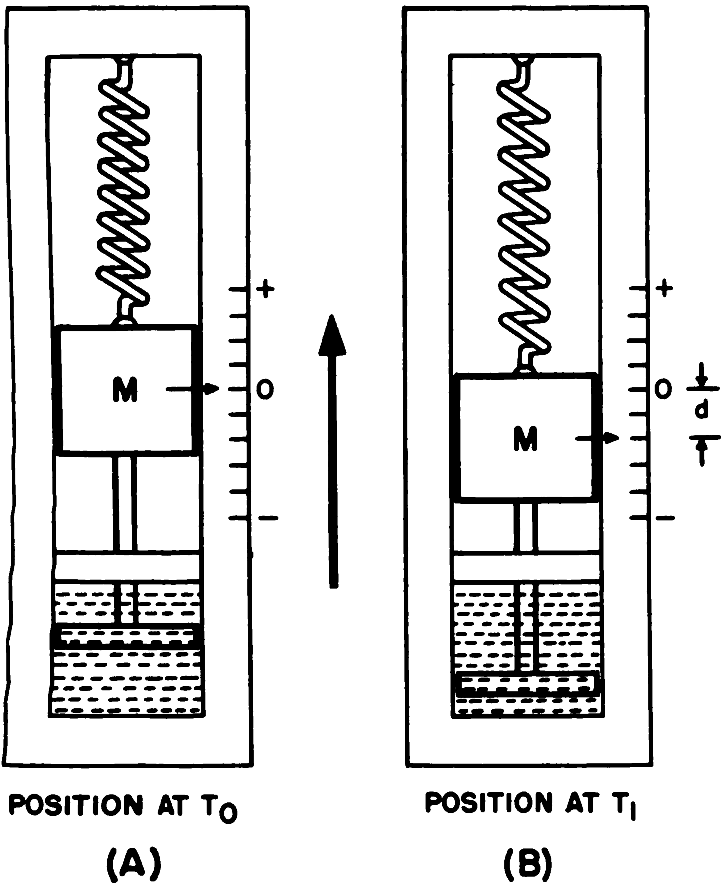


Figure 11–12.—Accelerometer operation.

force tends to oppose the movement of the mass, so damps its action. This damping force is proportional to the velocity of the mass weight and prevents or reduces oscillation.

A transducer or pick-off is not necessarily a basic part of the accelerometer but is usually built along with it. It converts the displacement of the mass within the frame to a proportional electrical signal. Electrical measurement of displacement therefore results in an output which is proportional to both force and acceleration.

The way in which the accelerometer operates can best be described by referring to figure 11-12. The mass (M) is suspended from the spring within the frame and at the time represented by t_0 is at rest and pointer attached to the mass is at some neutral point on the scale (fig. 11-12A). At time t_1 a force is applied to cause the frame and the structure to which it is attached to move in the direction shown by the heavy arrow. The mass, because of its inertia, tends to remain in its original position in space while the frame moves out from under it in the direction shown. This causes a displacement (d) of the mass or frame as shown in figure 11-12B. This displacement can be registered on a scale as shown or can be made to move a potentiometer arm to give an electrical signal proportional to the displacement. Remember, this displacement was caused by an external force. This force is proportional to the acceleration causing the movement of the entire structure, the missile, for instance. Then it follows that the output voltage is proportional to the acceleration of the missile.

We may summarize the information concerning accelerometers by saying that they all fundamentally consist of a mass and a spring housed in a case, and damped. When the case is shaken, for example suppose the missile suddenly veered off course, then a relative movement between the mass and the case is produced and a transducer or pick-off device of some type, which is incorporated in the instrument, produces an electrical signal proportional to the velocity or displacement of the mass with respect to the case. The mass

and the spring system in these components is said to have just one degree of freedom because the spring and the mass are permitted to move only in a straight line inside the case.

This detailed discussion of the servo system gives you a firm idea of the basic system with which you will be concerned. Nothing in this discussion however, should be construed to be the exact circuitry of any specific missile. For that, consult your missile manuals.

We shall further use this servo system in this discussion as a basic component of the electric, electrohydraulic and the electropneumatic control systems which follow in chapter 12.

QUIZ

1. The missile system responsible for maintaining the selected missile heading and attitude is the
   a. airframe system
   b. propulsion system
   c. control system
   d. guidance system

2. A guidance system determines
   a. the required direction of flight to direct a missile to a specific location
   b. the altitude and flight pattern
   c. amount of surface deflection necessary to hit a target
   d. the type of control, aircraft or radar, necessary to hit a target

3. What are the three classifications of control systems?

4. The servomechanism system in which the control operation is independent of the result is called a/an ---------- system.
   a. closed-loop
   b. discontinuous
   c. continuous
   d. open-loop

5. "On-off" and "bang-bang" systems are examples of what servo systems?
   a. Closed-loop
   b. Open-loop
   c. Discontinuous
   d. Continuous

6. What are the five basic components of a simple closed-loop servo system?

7. A sinusoidal input is one in which the input member is rotated a given amount
   a. in one direction only
   b. during the missile climb phase
   c. in one direction and then has reversed rotation
   d. so that the input angle increases directly with time

8. An error detecting device is a mechanical or electromechanical differential which gives an indication of
   a. the sum of the instantaneous values of an input and output
   b. the size and direction of an error
   c. the phase differential of an error
   d. the sum or difference of two signals

9. A controller is a power device that is controlled by
   a. the missile control surfaces
   b. the small error from the feedback loop
   c. small error signal received from the error detector
   d. the steady state error, since it is proportional to velocity of control surface movement

10. What determines how long the feedback signal in an external feedback system must be applied?
   a. The direction in which the missile turns
   b. The sensitivity of the control surfaces
   c. The sensitivity of the autopilot system
   d. The rate at which the missile turns

11. Referring to figure 11–10, if a horizontal force "F" is applied in the direction shown, the rate gyro will precess how many degrees away from the applied force?
   a. 18°
   b. 270°
   c. 90°
   d. 45°

12. What best describes "critical damping"?
   a. The missile continually oscillates about the desired output.
   b. The missile acts very slowly to achieve the desired output.
   c. The missile achieves the desired output in the shortest possible time after disturbance.
   d. The missile responds only to yaw and pitch acceleration commands.

13. When the autopilot detects deviation of the missile from its proper attitude, it corrects for this deviation by
   a. sending signals proportional to the size and type of attitude errors to the servo system which moves the control surfaces
   b. sending external feedback to the cross feed amplifier which in turn moves the control surfaces
   c. using radar signals from the guidance transmitter
   d. keeping the control surfaces steady until the amount of error is determined by the computer and then feeding back the necessary signal to move the control surfaces

14. In position control type servos the output
   a. is governed by pitch and yaw acceleration commands only
   b. attempts to follow the position of the input
   c. attempts to follow the position of the command guidance systems
   d. follows the algebraic sum of the signals from the rate and free gyros

15. Before any acceleration of the missile can be determined

a. a change of heading is experienced followed by a control surface movement

b. the rate and free gyros must both read zero

c. a control surface movement is experienced followed by a change of heading

d. the missile must be held on a constant heading

CHAPTER 12

CONTROL SYSTEMS

In this chapter we will discuss the electric electrohydraulic and the penumatic-electric control systems which are used in some missiles. A reference book on the fundamentals of hydraulics which is recommended as an introduction to the hydraulic section of this chapter is *Basic Hydraulics*, NavPers 16193. A number of hydraulic components were explained in chapter 6 of this text, in relation to power sources. These will be referred to throughout this chapter.

HYDRAULIC-ELECTRICAL CONTROL SYSTEMS

Figures 12-1 and 12-4 show two basic hydraulic control systems. The system in figure 12-1 consists of a drive motor, hydraulic pump, relief valve, reservoir or sump, accumulator, transfer valves and an actuator. The drive motor may be an electric or an air motor, as explained in chapter 6. The motor usually drives a positive displacement hydraulic pump. The type pump depends upon the design characteristics of the system in regard to size, weight, and pressure output. Based on these considerations it could be of the axial piston, reciprocating, or gear type. The supply of oil to be used in the system comes from the sump. The sump also receives the return oil after it has operated the actuator. After leaving the pump the oil passes through a relief valve. You will remember from your study of *Basic Hydraulics* that a positive displacement pump is one in which a definite

volume of liquid is delivered for each pumping cycle regardless of the resistance offered to flow. Should the outlet of such a pump or any other part of the system be blocked so as to prohibit flow entirely, then one of two things would occur, either the drive motor would stall or some part of the system, oil line, joint or other component, would rupture. For this reason the relief valve is installed in the hydraulic line after the pump and before the accumulator. When the pressure output becomes too great, the relief valve opens at a preset value and passes the oil back to the sump.

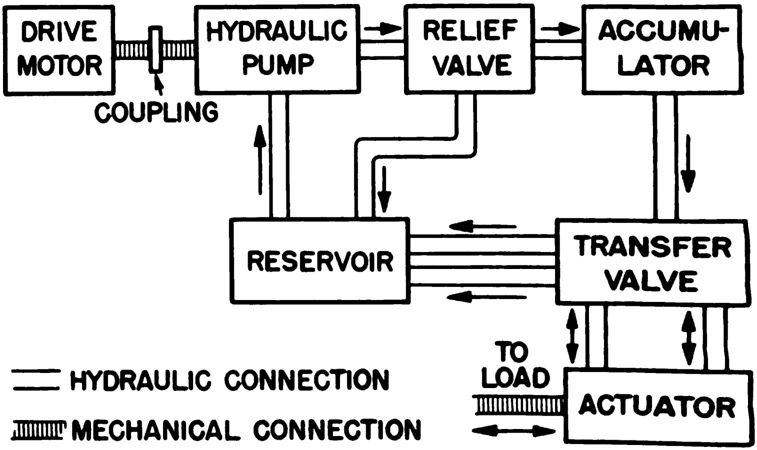


Figure 12–1.—Basic hydraulic control systems.

The output of a positive displacement pump is pulsating. The accumulator used in the system shown in figure 12–1 helps to smooth out the pulsations or pressure surges. A pulsating flow in the hydraulic system would cause vibration of components and an unsteady operation of the control devices to which the actuators are connected.

Accumulators are of two types, either the floating piston type or the diaphragm type. These are shown in figure 12–2.

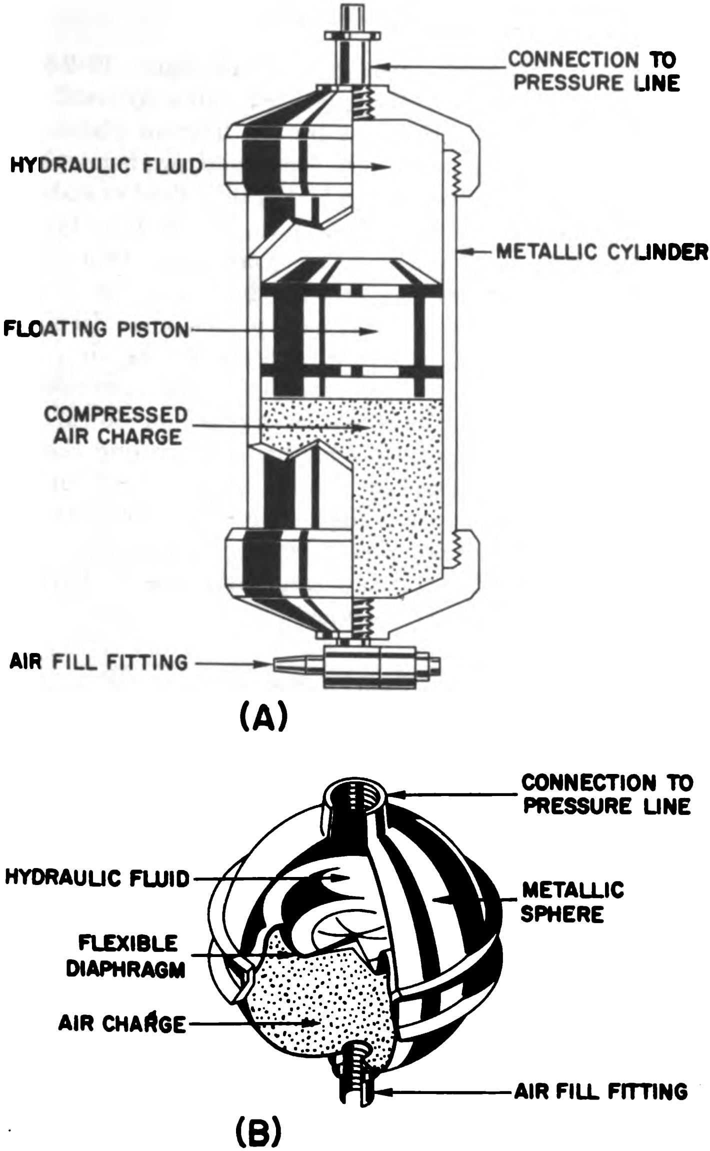


Figure 12–2.—Hydraulic accumulators.

Accumulators

The floating piston type accumulator, figure 12–2A, consists of a metallic cylinder separated into a hydraulic fluid chamber and an air chamber by the floating piston. The diaphragm type, figure 12–2B, consists of two hemispherical pieces of metal separated into a hydraulic fluid chamber and an air chamber by a flexible diaphragm. In both types the air chamber is charged with air compressed to a pressure corresponding to the line pressure desired in the hydraulic system; this air exerts a force on the piston, or the diaphragm. If the line pressure builds up higher than the air pressure in the accumulator, fluid is forced into the hydraulic fluid compartment. This fluid pushes the piston down, or depresses the diaphragm, thus further compressing the air in the air chamber. During periods of peak load, or pump lag, the compressed air tends to force fluid from the accumulator back into the hydraulic system. Thus, by building up pressure in the accumulator, variations in hydraulic-system line pressure are smoothed out.

Transfer Valve

After passing through the accumulator, the fluid enters the transfer or pilot valve illustrated in figure 12–3. This pilot valve is positioned automatically depending on the desired action of the load. In figure 12–3A fluid flow will be as indicated by the arrows for one direction of actuator movement and as shown in figure 12–3B for the opposite direction of actuator movement.

Actuator

The purpose of a hydraulic actuator is to transform fluid pressure into mechanical force necessary for moving a control device. A basic hydraulic actuator consists essentially of a cylinder, with suitable intake and exhaust ports, fitted with a piston and connecting rod. The actuator shown in figure

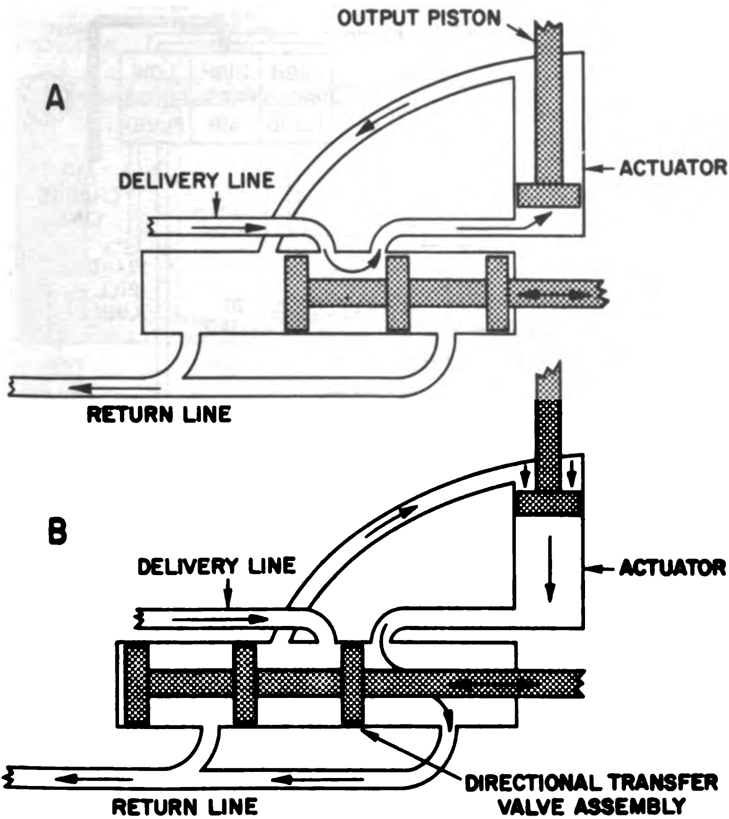


Figure 12–3.—Transfer valve.

12–3 is a double-acting piston type. In that actuator the pressurized hydraulic fluid can be applied to either side of the actuator piston, thus producing motion in either of two directions. On the upstroke fluid under pressure enters the cylinder below the piston, forcing the piston up and forcing the fluid above the piston back to the reservoir. The down stroke of the actuator piston results when fluid enters the cylinder above the piston. In this instance the fluid below the piston returns to the reservoir.

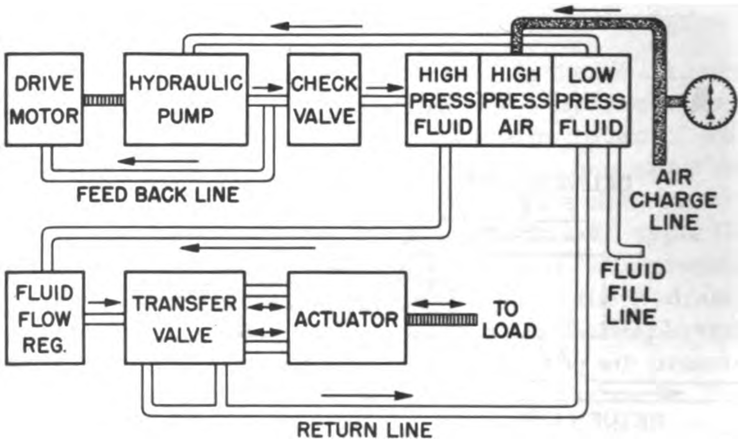


Figure 12–4.—Basic hydraulics control system.

The system shown in figure 12–4 is essentially the same as that of 12–1. The purpose and operation of the drive motor and the hydraulic pump are identical. You will notice, however, that there is a feedback line from the high pressure side of the pump to the drive motor. The purpose of this line is to transfer the pressure output to a switch or regulator controlling the speed of the drive motor. The pressure output of the pump is dependent upon the speed of the drive motor; hence when the output pressure of the pump reaches some predetermined value, the drive motor is slowed or stopped. In effect, this acts much the same as the relief valve in the previous explanation of the system shown in figure 12–1.

Reservoir

The output of the pump is led to the reservoir or sump. This sump plays a double role in this particular system. It acts both as an accumulator and as a storage for reserve hydraulic fluid. Refer to figure 12–5 for a more detailed illustration of this. The left-hand side of the sump shown in that figure is the high fluid pressure side and the right-hand

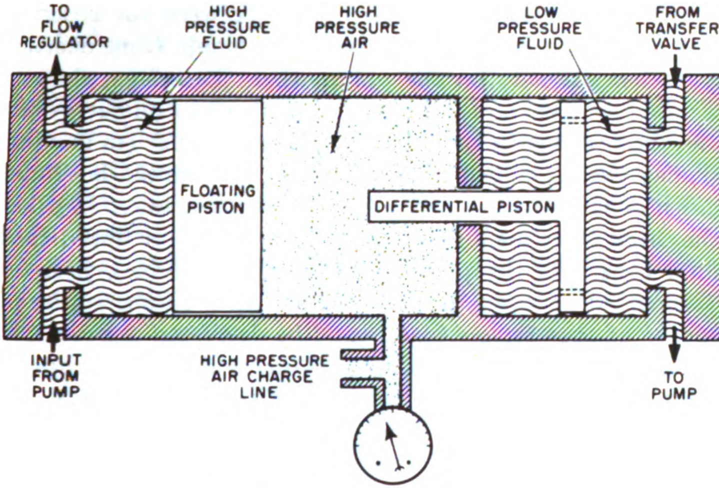


Figure 12–5.—Hydraulic sump.

side is the low fluid pressure side. The center section of the sump is the high pressure air chamber. This center section is charged with air through a fill valve and the amount of pressure is monitored on the gauge shown. The pressure to which the chamber is charged is dependent upon the value prescribed for a specified system. The pressurized air, (we shall arbitrarily set this at 1000 lbs sq in) forces both pistons to the respective ends of the sump. The force on each piston is not the same, however. You will notice that the area of the high pressure piston upon which the high pressure air acts is greater than that of the differential piston. As a result the force on the storage or low pressure side is less than that on the high pressure side. The pressure on the low side provides the back pressure required to force the return fluid to the pump. The reserve section storage is to provide hydraulic fluid to replace that lost through leakage and to provide space for expansion of the fluid due to heat. This reservoir acts in the same manner as the floating piston accumulator explained with the system of figure 12–1.

Check Valve

The check valve shown in the line between the reservoir and the pump is used to prevent the sump from exerting a reverse pressure on the pump when the system demand is low. For example, if there is no demand on the system and the pressure in the sump is up to maximum (in our particular case 1000 lbs sq in), then the pump would be slowed down or stopped as a result of the feedback line. Without the check valve the high pressure in the reservoir would force fluid back into the pump since there would be a pressure differential between the two parts. As a result, rapid response of the entire system woud be decreased appreciably.

After passing through the sump the fluid passes through a filter before reaching the flow regulator. The filter is a screening or straining device used to clean the hydraulic fluid, thus preventing foreign particles and contaminating substances from remaining in the system.

Filters

Filters may be located in various places in the system and not necessarily in the location shown in figure 12–4. To perform the exacting duties of hydraulic maintenance efficiently, it is necessary for you to understand the location, construction and operating principles of filters used in the system. Main system filters may be located in the pressure line, return line or in the sump or reservoir.

Filters may be grouped into two classes—those using the principle of edge filtration and those which employ the principle of screening. The CUNO type filter belongs in the first class and the MICRONIC type filter belongs in the second class. Of these the micronic type has been found to be the most effective.

Micronic Filters

There are many variations of the micronic or absorption-type filters. In general, however, the construction, design, and arrangement of parts of this type of filter are determined by the amount of fluid in gallons-per-minute to pass

through it. The filter is the replacement element, consisting of a head assembly, filter element and case.

The micronic type filter was especially designed for hydraulic systems that require exceedingly close tolerances between working parts. The filtering element, or cartridge, is made of specially treated cellulose formed in convolutions (wrinkles) and designed so that solids greater than 10 microns (0.000394 inch) are removed.

Various models of this type of filter are made to conform to the capabilities and requirements of the hydraulic systems

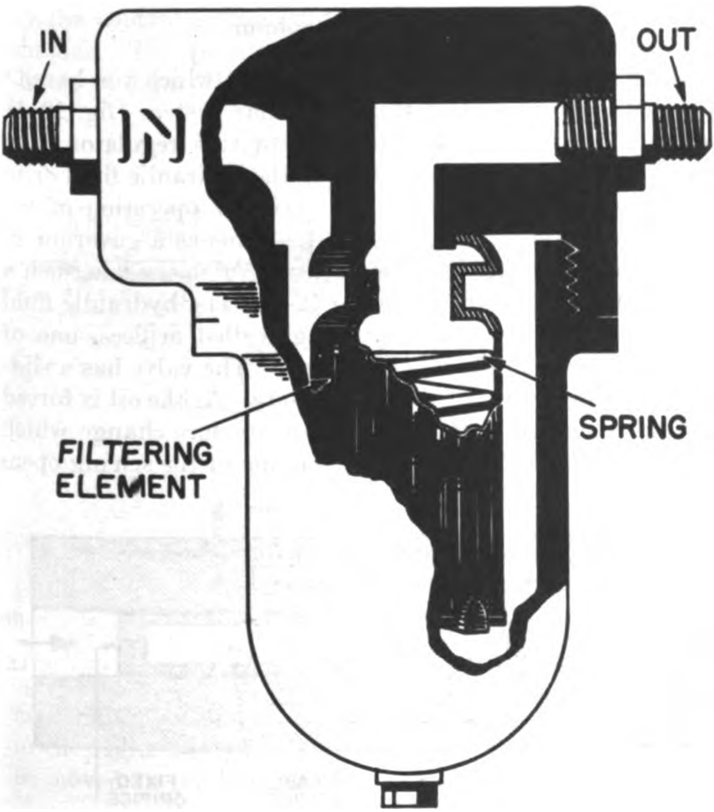


Figure 12–6.—Micronic filter.

in which they are installed. In addition, they are made in types that are designed according to the place where they are to be installed. Thus there may be one for the reservoir, another for the pressure and return lines, and still another for the reservoir vent line. When a filter is placed in the reservoir vent line, its purpose is to filter dust and other contaminating substances from the air.

Figure 12–6 is an illustration of a micronic filter. This unit consists of a head containing the in-port and the out-port, the case and the filtering element.

Fluid Flow Regulator

The fluid flow regulator is a component which you haven't seen yet. It appears in this particular system (fig. 12–4) before the actuator. The purpose of this regulator is to maintain a specified rate of flow of the hydraulic fluid or to govern, to a certain extent, the speed of operation of the actuator. In effect it acts much the same as a governor in a mechanical system. A flow control value used in such a regulator is illustrated in figure 12–7. The hydraulic fluid passes through two small openings called orifices, one of which is fixed and the other variable. The valve has a sliding piston held open by spring pressure. As the oil is forced through the fixed opening there is a pressure change which reacts against the spring. The reaction of the spring opens

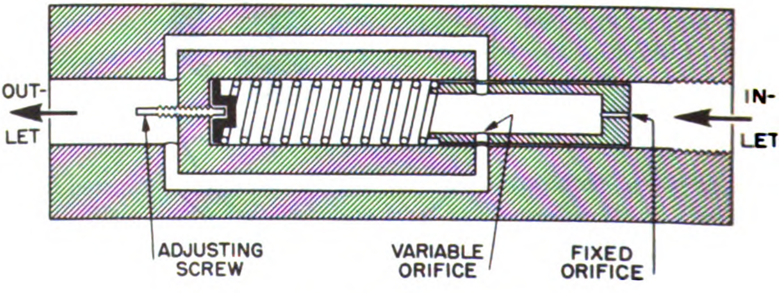


Figure 12–7.—Flow control valve.

and closes the variable orifice (outlet) so as to maintain this pressure drop. Maintaining a constant pressure drop maintains a constant flow irrespective of the output pressure. This amount of flow is regulated by the spring tension adjusted by the screw shown in the figure.

Servo Valves

The output of the flow regulator is led to the servo valve shown in figure 12–8. This valve consists of a solenoid and a pilot valve or transfer valve. The solenoid is energized by the control system which will be discussed later in the chapter. The pilot valve is similar to the transfer valve shown in figure 12–3. The unit pictured is elementary in

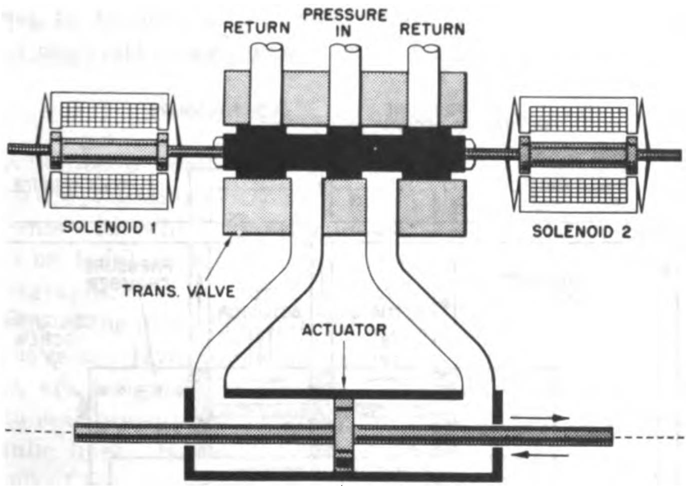


Figure 12–8.—Servo valve.

operation in that it has but two positions, either on or off. Energizing solenoid 1 causes the pilot valve piston to move to the right and energizing solenoid 2 causes the piston to be moved to the left. As the piston moves in the cylinder, it causes ports to be opened. In addition, an arm connected to the piston rod could contact a limit switch, not shown,

when a port is opened fully. Breaking the contact of the limit switch would deenergize the solenoid preventing further movement.

This on-off method of operation is not always suitable for missile system operation. The on-off method gives positive movement to the control surfaces, either full up or full down, full right or full left in direction. A finer control is often more desirable. The arrangement shown in figure 12–9 provides this control.

Another action occurs as a result of the pilot valve piston movement. Notice, as it moves to the left, the volume of fluid contained on the left side between the fixed orifice and the end of the piston and the variable nozzle is decreased by an amount directly proportional to the amount of piston movement. At the same time the volume on the right hand

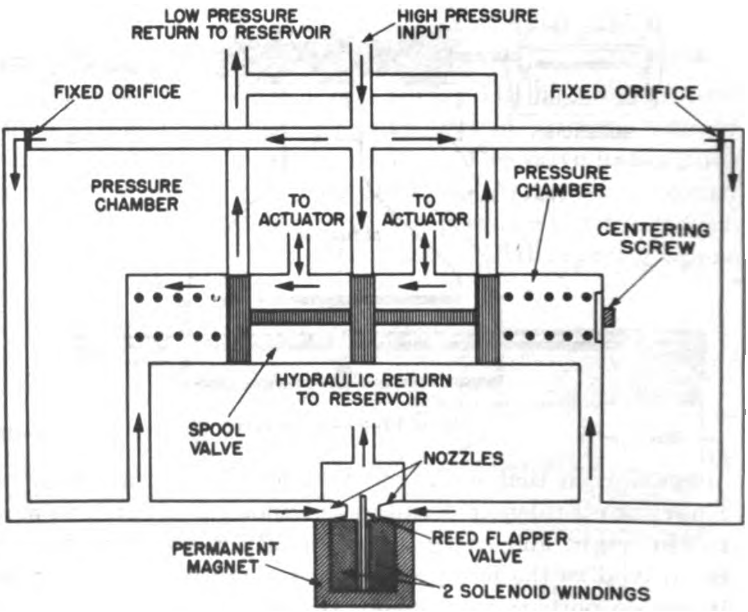


Figure 12–9.—Servo valve.

side of the piston is increased. The changes in volume produce a resultant pressure change on both ends of the pilot piston tending to oppose any movement. This pressure change is proportional to the movement of the piston. This might be considered to be a negative feedback. The decrease of volume on the left side is accompanied by an increase in fluid flow through the left nozzle, and the increased volume on the right side is accompanied by a decrease in fluid flow through the right nozzle. The result is a positive feedback action proportional to the rate of movement. The combination of the negative and positive feedback results in a hydraulic amplifier. The movement of the pilot piston either right or left performs the same function as the transfer valve described for the first system.

The actuator for this system is much the same as that explained for the system shown in figure 12–1.

Hydraulic Seals

A number of components have been discussed in connection with the preceding systems. These are not all the basic components with which you should be concerned. You should also be familiar with the ones discussed in the following paragraphs.

One of the more fundamental parts of a hydraulic system is the SEAL. Hydraulic seals, sometimes referred to as packings, are designed for a twofold purpose. Their function is to seal pressure in as well as to keep air out of the hydraulic lines. Basically, all seal designs may be classified as one of four general types.

The CHEVRON seal is manufactured in two forms—natural rubber or synthetic rubber. Seals of this type are generally V shaped and always require reinforcement. The point of the V on this seal is supported by a female packing former, and the open end of the V has a male packing former as support. These formers are made of fiber, plastic or metal.

CUP seals are made both of natural and synthetic rubber and are used on various units such as selector valves. Cup

seals are sometimes used to seal against dirt and air as well as against fluid. An important point to remember is that cup seals are effective in one direction only. Where required, shim stock should be used to protect the lips of these seals during installation.

C-Ring packing, the most commonly used type of seal, is used to prevent internal and external leakage in stationary and moving parts. O-ring seals are doughnut-shaped and are used for effective sealing in both directions. Like cup seals they are made of either natural or synthetic rubber and are used in many units such as piston valve heads and selector valve sleeves.

The sealing characteristics of O-ring seals is their ability to spread against the groove in which they are installed when pressure is applied on one side or the other of the working part. In all systems having pressure higher than 1500 lbs/sq in leather back up rings are used to protect the O-rings. The prime function of the leather back-up ring is to prevent extrusion of the doughnut seal under excessive pressure. It is highly important that seals specified by the manufacturer of a unit to be used to replace O-rings.

Metallic seals, more commonly known as crash washers, are designed for high pressure use as air valve seats on accumulators, and for seats on fittings which screw into units. This type of seal, used on non-moving parts, is generally made of soft aluminum.

Restrictors

Restrictors have been previously mentioned in relation to fixed or variable orifices. The purpose of these restrictors is to limit the rate of flow in both directions in a line. In doing so, these units cause the mechanism being actuated to move more slowly.

An orifice and a variable restrictor differ only in construction. The size of an orifice is usually fixed, whereas the size of the opening in a variable restrictor may be changed. An orifice is primarily a fitting containing a small passage.

Fluid entering one end of the fitting must traverse the small passage before flowing from the opposite end. The housing of the variable restrictor, illustrated in figure 12–10, has two ports and an adjustable needle valve. The size of the passage through which the fluid must pass may be adjusted

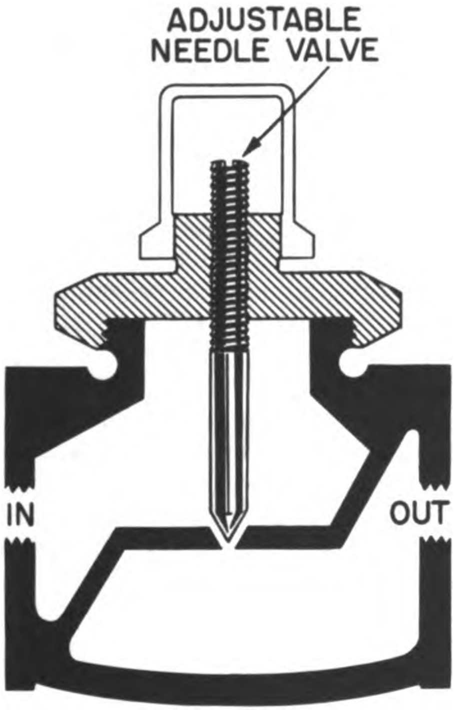


Figure 12–10.—Hydraulic restrictor.

by screwing the needle valve in or out. This is not the only form the variable restrictor may take. You have previously encountered a variable restrictor in the flow regulator wherein the movement of the piston in the regulator cylinder opened or closed the outlet port an amount dependent upon the regulating spring pressure.

Manifolds

Manifolds are another elementary component of hydraulic systems. These are junction boxes for the hydraulic lines and are designed to save weight and space by eliminating many fittings. This also tends to lessen the danger of leakage.

Manifold blocks are located at branch-off points of pressure lines to selector valves; working lines to cylinders, and return lines from selector valves.

Summary

Other components such as pressure regulators, actuators, and flow regulators have been covered sufficiently in both this chapter and chapter 6 of this text. By your study of *Basic Hydraulics* (NavPers 16193) and this chapter you should have an understanding of the principles of hydraulics, and the components of the systems.

Electric-Hydraulic Components

The method of using electric-hydraulic components in a missile is illustrated in the following explanation of a roll control system. The operation of other electric-hydraulic control features, such as yaw and pitch control, will be found in the instruction books peculiar to the missiles with which you will work.

The system using electric-hydraulic control components to keep the missile from rolling might operate as shown in the block diagram of figure 12–11. It is a simple system and is used on a missile which has little tendency to roll in flight, that is to say the missile is aerodynamically stable.

Only proportional control is used in this system; it reacts to information which tells the amount of variation of the airframe from level flight. To do this, the signal is proportional to the deviation and is called a displacement signal. In this particular system rate control is unnecessary.

Notice that the components can be closely related to the basic control block which was presented in chapter 10. The

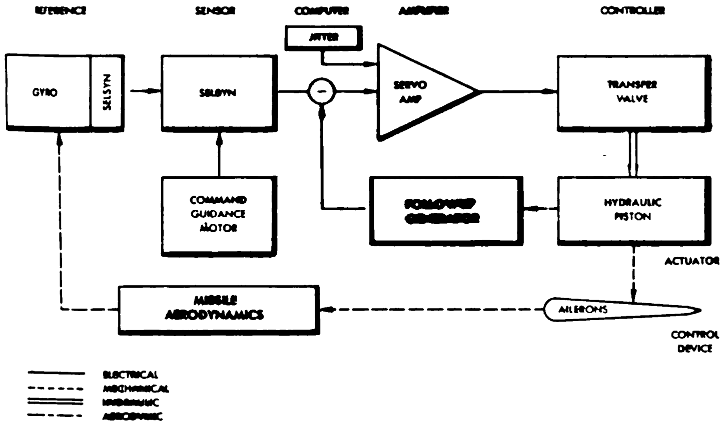


Figure 12–11.—Electric-hydraulic roll control system.

gyro acts as the reference for the system. A pick-off is connected to the gyro and senses any roll which the missile might experience. If any roll is detected, the pick-off produces an error signal. The correction to the servo amplifier is the difference between the follow-up signal and the gyro signal. This voltage is amplified and increased in power so that it can operate the controller. The controller in this case is the hydraulic transfer valve activated by the servo solenoids or servo valves previously covered. The transfer valve causes the actuators to move the control surfaces to connect for the signalled error.

ELECTRIC-PNEUMATIC CONTROL SYSTEMS

The second of the three systems of power transfer for control systems is the electric-pneumatic system. Pneumatic systems use air as the transfer medium in much the same manner as hydraulic systems use a liquid. Before we discuss the system and its components it would be useful to review a few of the properties and laws governing the behavior of gases and the types of gases used in missiles.

If you put a pint of milk in a quart bottle, the milk does not expand and fill the entire bottle. However, if you

puncture an inflated tire, the air that was inside escapes and occupies much more space than it did formerly. You can easily measure the volume of a liquid, but the volume or the space that a gas will occupy depends upon the pressure to which it is subjected. Gases expand when heated, and they contract correspondingly when cooled. Since the volume of gases vary considerably depending on the pressure and temperature, we must establish a standard of temperature and pressure for measuring the volume of gases.

We need, therefore, an understanding of absolute pressures and temperatures. Although we live at the bottom of an ocean of air, we do not feel the pressure which the atmosphere exerts on us because the pressure is nearly equal in all directions. This pressure has definite limitations. Atmospheric pressure at sea level will support a column of mercury just 30 inches high. This means that the average atmospheric pressure at sea level is 14.7 lbs/sq in.

In all problems involving the laws of gases, where pressure is to be computed it should be figured in pounds per square inch ABSOLUTE, which is the gauge pressure plus 14.7 psi at sea level. Normally, pressures given in instruction books or text books are given as gauge pressure readings and are automatically corrected for absolute pressure if such readings are required, or if the distinction would be significant. However, in this chapter where the gas laws are illustrated you must keep the distinction in mind: the gas laws are based on absolute pressures and not on gauge pressures. This is, as you have seen, a simple matter to take care of. If the pressure is given as gauge pressure, add 14.7 psi; if the pressure is given as absolute, and the gauge pressure is desired, then subtract 14.7 psi, assuming sea level in both cases.

The absolute temperature scale resulted from a series of experiments with hydrogen gas. It was found that if hydrogen gas at 0° C was cooled so that its temperature dropped 1° C, the gas contracted to 272/273 of its original volume. As the temperature was further decreased or increased, over a fairly wide range of temperatures, the gas

volume increased or decreased by 1/273 of its original volume for each degree centigrade change of temperature. From this experiments you might deduce that if the gas had been cooled to −273° C, it would have contracted to nothing. However, gases change to liquids before such low temperatures are reached, and the significance of the −273° C mark is that it is the point at which all molecular motion of a gas is believed to cease. This point has been taken as absolute zero, and is equal to −459° F or −273° C. More will be stated about this under Charles' Law later in the chapter.

There are three temperature scales with which you might be concerned in using missile manuals. These are the Fahrenheit, the centigrade and the absolute or Kelvin. The centigrade scale is constructed by using the freezing point and boiling point of water, under standard conditions, as fixed points of zero and 100 respectively with 100 equal divisions between. The Fahrenheit scale uses 32° as the freezing point of water and 212° as the boiling point, and his 180 equal divisions between. The absolute scale is constructed with its zero point established at minus 273° C or minus 459.4° F. The relations of the fixed points of the scale are shown by figure 12–12.

Always make sure you know what system of temperature measurement is being used, and that you know how to convert one to the other. Any standard handbook will enable you to do this.

Following are the laws concerning gases. The first of these is Boyle's Law.

THE VOLUME OF ANY DRY GAS, THE TEMPERATURE REMAINING CONSTANT, VARIES INVERSELY WITH THE PRESSURE ON IT; THAT IS, THE GREATER THE PRESSURE, THE SMALLER THE VOLUME BECOMES.

The law is also stated as an algebraic formula:

$$V_1P_1 = V_2P_2 \text{ or } \frac{V_1}{V_2} = \frac{T_2}{T_1}$$

where V_1 and P_1 refer to the original volume and pressure and V_2 and P_2 refer to the new volume of gas and the new

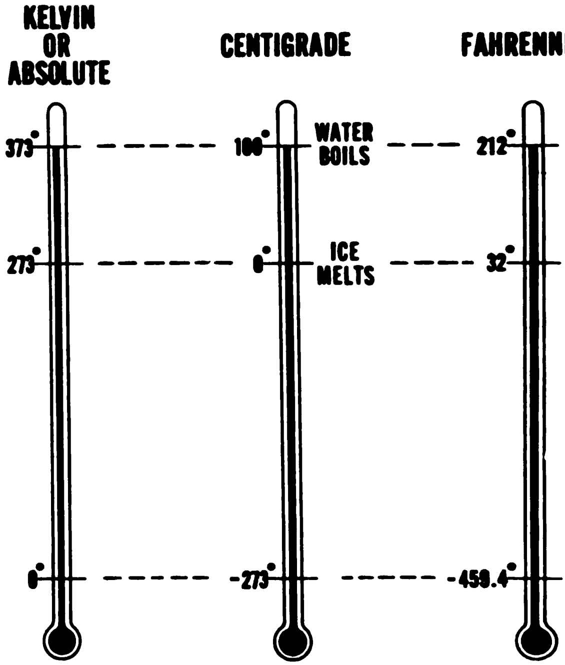


Figure 12–12.—Temperature scales.

pressure which causes it. This equation is true providing only that the temperature has remained the same.

ALL GASES EXPAND AND CONTRACT TO THE SAME EXTENT UNDER THE SAME CHANGE OF TEMPERATURE, PROVIDED THERE IS NO CHANGE IN PRESSURE. In general, when the pressure is kept constant, the volume of a gas is proportional to its absolute temperature. This is known as Charles' law.

This, in equation form, becomes:

$$\frac{V_1}{V_2}=\frac{T_1}{T_2}$$

$$V_1T_2=V_2T_1$$

Finally, since the volume of a gas increases as the temperature rises, it is reasonable to expect that if a certain

mass of gas were heated, and yet confined in the same space, the pressure would increase. Very careful experiments have been carried out to determine the pressure coefficient of a gas and the results have shown that the pressure of any gas kept at a constant volume increases for each degree centigrade very nearly 1/273 of the pressure at 0° C. Because of this finding it is convenient to state this relationship in terms of ABSOLUTE TEMPERATURES, so for all gases at constant volume, the pressure is proportional to the absolute temperature; and in equation form, Charles' law becomes:

$$\frac{P_1}{T_2}=\frac{T_1}{T_2} \text{ or } P_1T_2=P_2T_1$$

where P_1 and T_1 are the original pressure and temperature and P_2 and T_2 refer to the new pressure and temperature. In using this formula do not forget to convert the pressure and the temperature to absolute units.

The general gas equation comes from a combination of Boyle's law and Charles' law, and it is expressed by combining their equations into one. That is:

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

These gas laws and physical properties of gases will help you to understand certain safety requirements regarding gases. They also point out why it is possible to place a large volume of gas in a small container and explain the physical changes that occur as a result. For instance, in charging a cylinder of constant volume to a higher pressure, the temperature of the gas will rise, or by increasing the temperature of a cylinder already charged, the increase will cause an increase of pressure within the cylinder or flask.

In your work with missiles you will come to use pressurized gases in many ways. It is or may be used as the fundamental source of potential energy for driving air motors, turbines and in some instances to power servos. The gas may be in the form of high pressure air stored in a flask or it may result from the combustion of some solid fuel, such as a powder grain. The means by which this potential energy is used to drive motors and turbines has been explained

in chapter 6 of this text. The manner in which it may be used to operate servos is much the same as that used to operate hydraulic systems. Since both gas and hydraulic liquid are fluids, the differentiation being that the former is compressible and the latter non-compressible, they can both be used in pressurized systems. The principles for the operation of valves regulators, manifolds and other components are the same for both types of fluids.

ELECTRIC CONTROL SYSTEM

An ELECTRIC control system employs electrically driven components throughout. The desired heading of the missile is established by an electrically driven gyro. The sensor unit or pick-off is of the potentiometer, synchro or reluctance type. A rate signal is obtained from an electrically driven rate gyro or from an electronic rate circuit operated by the displacement gyro. Electronic amplifiers or magnetic amplifiers provide for both voltage and power amplification. The controller is a device that uses a signal to vary the electric power which moves the control surfaces. In the case of the electric system the type of controller depends upon the type of actuator to be controlled.

Electrical energy can produce mechanical motion by means of the magnetic force it can generate. An electric actuator makes use of this magnetic force through a solenoid or a motor. The solenoid does not normally have the strength to cause airfoil movement, hence small high speed motors usually are used for this purpose. A small motor running at high speed has the power potential necessary to move airfoils of a missile if it is connected to them through a gear train. The mechanical advantage of the gear train makes it possible to exert a large torque on the control surface pivot. This motor is of either the CONSTANT SPEED type operating through a clutch or a VARIABLE SPEED MOTOR.

An advantage of the all-electric system of control is that it requires only one power source for operation so the overall weight of the missiles is reduced.

The use of a motor as an actuator has the disadvantages of causing a lag in the control surface response. The lag may be so great that it causes the system to operate with insufficient sensitivity or with a tendency to oscillate. The lag is due to inertia of the motor. That is to say, the lag is due to its resistance to starting from a dead stop and attaining a very high velocity in very short time. A method of overcoming this disadvantage, to a certain extent, is to use a constant speed motor with a clutch arrangement to control the output.

Variable Speed Actuator

The variable speed actuator operates through a gear train as shown in figure 12–13. A signal is sent to the motor which causes it to rotate in either direction, depending upon the sense of the signal.

The motor turns at speeds approximately proportional to the strength of the signal. Since the motor is coupled

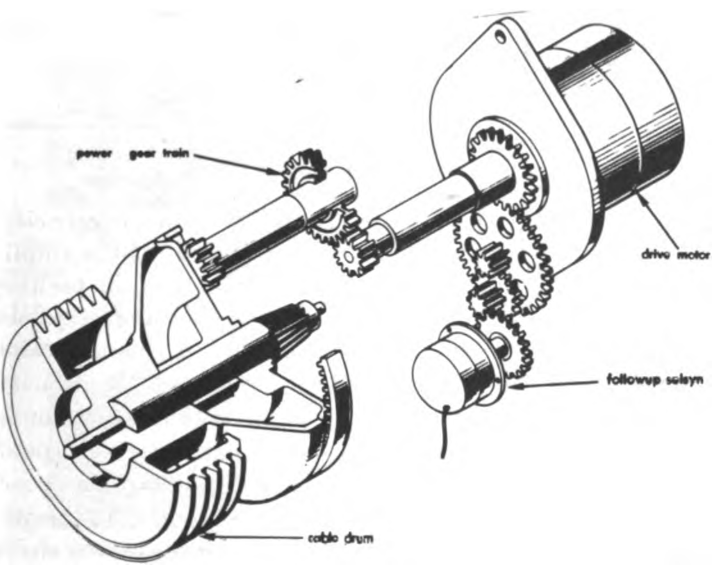


Figure 12–13.—Variable speed actuator.

through the gear train to the control surface, the control surface movement is proportional to the speed of the motor and therefore to the signal strength.

The signal to the motor must be of high power since it supplies the driving power to the motor. In some systems, the variable speed motor could be driven directly by the output of an electronic power amplifier or a magnetic amplifier.

The controller shown in figure 12–14 converts the power of the controller motor to the three channel variable speed motors. The generator which is shown in block form is

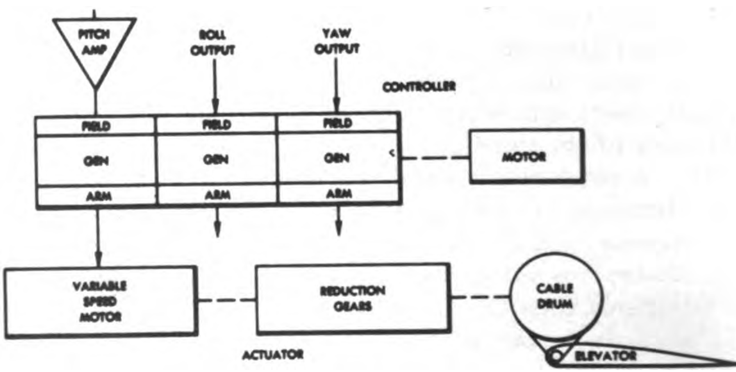


Figure 12–14.—Pitch electrical system.

of the amplidyne type as explained in *Basic Electricity*, chapter 17. We shall assume that the output of the amplifier, in this case the pitch amplifier, increases in the positive direction. The larger output increases the magnetic field of the pitch generator. The control field of this generator is sensitive to both the level of the input and the polarity of the input. Therefore, as the output of the generator is increased from zero to a value above zero, the variable speed motor is caused to rotate in a specific direction at a speed dependent upon the requirements of the system. The transmission of this power puts an additional load on the shaft of the controller drive motor.

The controller drive motor must maintain a reasonable constant speed regardless of the load. Otherwise, if the pitch output decreased, the speed of the motor, and consequently the output of the roll and yaw generators, would decrease at the same time. This speed variation would cause undesirable cross-coupling between channels because the pitch signal would affect the other channels and vice versa.

The effects of inertia when starting and stopping a variable speed motor can be eliminated by using a drive motor

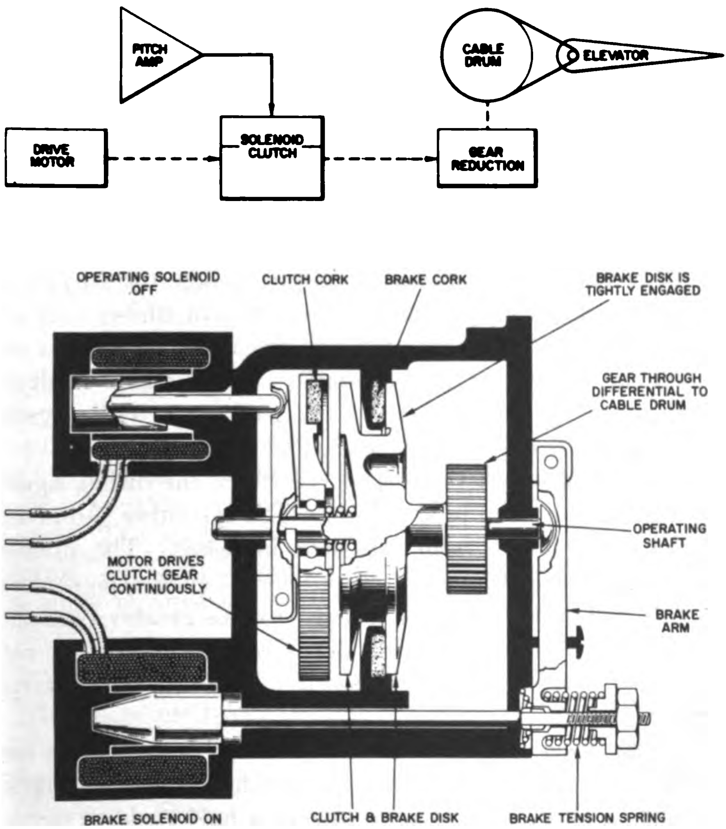


Figure 12—15.—Electrical system using clutches.

which runs continuously and maintains a rather uniform speed. In this case the motor is connected to the control surface through a clutch which serves as the controller for the system. This clutch varies the power transmission from the motor to the control surface. The use of two clutches and a gear differential would allow control in both directions.

Figure 12–15 shows a system output using clutches. The clutches are operated by using solenoids which are powered by the pitch, roll or yaw amplifiers.

On-off Control

ON-OFF control results when relays are used for controllers in an electric system. Normally such a system produces either full control surface deflection or none at all, since there is no way to distinguish small errors from large errors. The use of a DITHER SIGNAL can produce action which depends on the amount of error signal. A dither signal creates small oscillations in a control system. This low frequency signal (approximately 25 cycles) is generated by a signal from an electronic oscillator or generator, or it may be created by vibrating relay contacts. This signal is made to combine with the guided missile error signals. The purpose of the dither is to produce smoother action.

An illustration of the method in which the dither signal operates is shown in figure 12–16. The top curve shows the error signal starts from zero and increases. The middle curve shows that the on-off output signal moves the surface to full deflection when the signal becomes greater than the range of no action (dead spot). This dead spot is not desirable because small errors will not produce corrective action.

In the lower curve the rate of surface movement is dependent on the error signal strength. If no signal is present, a short output pulse during a half cycle of dither is canceled by a similar opposite pulse during the other half

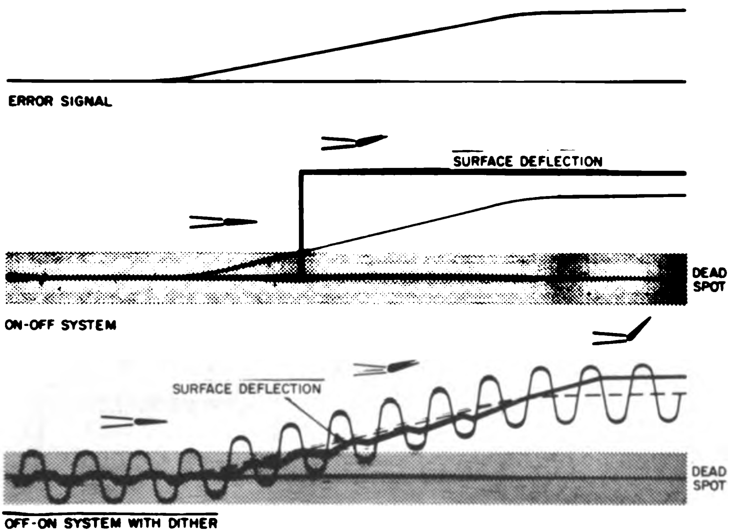
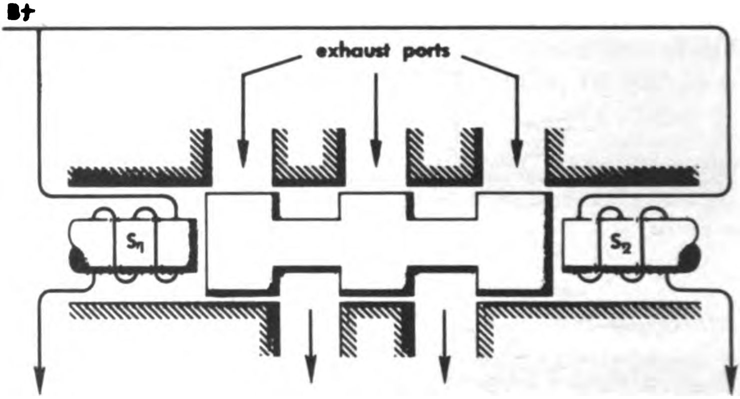


Figure 12–16.—Dither signal action.

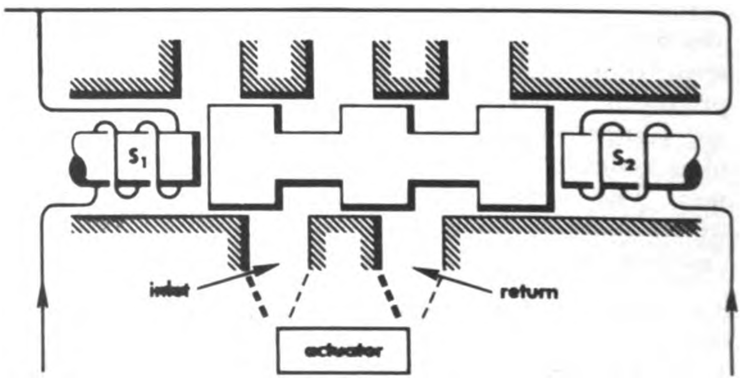
cycle, and a vibration of the airfoil about the streamline position results. When even a small error signal appears, the time of output in one direction increases and the surface moves further in one direction. As the error signal increases, the time during each dither cycle in which motion is produced becomes greater. The surface then moves in larger jumps. This shows that the rate of surface movement is roughly dependent upon the strength of the input signal. The on-off system, then, approaches proportional control. A disadvantage of the system is that movement of the surfaces must be in steps rather than continuous.

Solenoids

There are electrical components used in the all-electric, electro-hydraulic and electro-pneumatic control systems which are more common within these systems than any other component. Some are relatively simple; others, not so simple. The solenoid is perhaps the simplest component



(A)



(B)

Figure 12-17.—Double acting solenoid.

within these systems. It consists of a coil of wire wrapped around a hollow cylinder. When an electric current is passed through the coil, a magnetic field is set up within it. By placing a movable soft iron core in the hollow cylinder the core can be made to move back and forth as a result of the magnetic field generated. The tendency of the magnetic field is to center the core within the coil when the current is flowing. Figure 12–17 illustrates how these solenoids are put to work. This particular case uses a double acting solenoid. A soft iron core is attached to either end of a transfer valve and the solenoids are oriented about this core in such a manner as to actuate the valve when either one or the other is energized. In (A) of figure 12–17 the current flow through solenoids S–1 and S–2 is equal and the valve piston is centered in the closed position. In (B) of figure 12–17 we assume that the current flow in S–2 energizes that solenoid and pulls the piston to the right and the valve ports are opened. By causing a greater current to flow in S–1 than in S–2 the valve piston is moved to the left and the ports are again closed. This is simply one of the uses to which a solenoid may be put.

Relay switches are used for remote control of heavy-current circuits, transfer of power sources (such as from external to internal), and other applications. A relay switch consists of a coil or solenoid, an iron core, and fixed and movable contacts. Small wires connect the solenoid coil terminals with the source of power which is the control signal. When a control signal is present, an electromagnetic field is set up around the coil.

In the relay switch shown in (A) of figure 12–18 the iron core is fixed. When the control signal is present, the core is magnetized by the field set up around the coil. The pull of the core on the piece of soft iron overcomes the force of the spring thus closing the contacts. This action completes the heavy-current circuit. When the control signal is removed, the field around the coil collapses. Then the spring separates the contacts, breaking the heavy-current circuit.

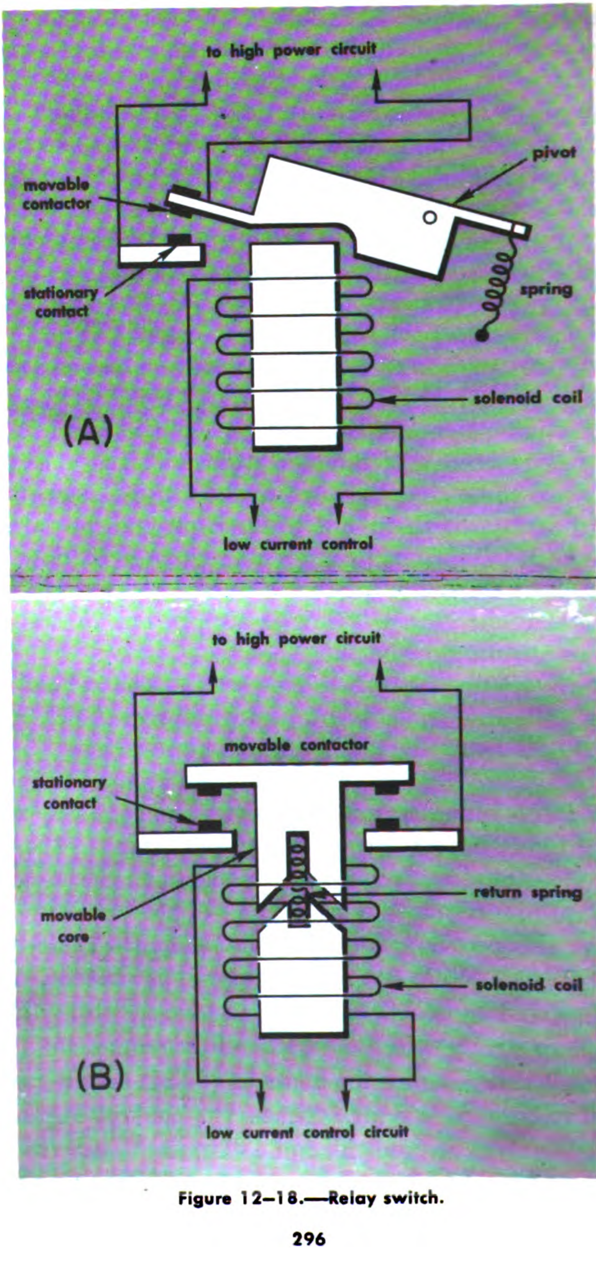


Figure 12–18.—Relay switch.

Another type of relay switch is one in which part of the core is movable as indicated in (B) of figure 12–18. Contacts are attached to the coil mounting but insulated from it. When the control switch is closed, the field around the coil causes the movable parts of the core to be drawn into the coil, closing the contacts and completing the heavy-current circuit. When the control switch is opened, the field around the coil collapses and the spring returns the movable core to its original position, separating the contacts.

The more quickly a circuit carrying a large current is opened, the less it will arc and the less the switch contacts will be burned. Relay switches used to control the circuits of large motors have strong springs which open the contacts quickly.

Relay switches have either an insulating spacer on each coil terminal or an insulating spacer on one coil terminal and a metal spacer on the other. If a metal spacer is used, it grounds the coil terminal to the case. Thus, no ground wire to that terminal is required.

A component of control systems which may be used in the power amplifier circuit is the magnetic amplifier. The magnetic amplifier is used for controlling motors, regulating the output voltage of generators, and it is frequently used in connection with servomechanisms.

Magnetic amplifiers are devices which control the degree of magnetization in the core of a coil in order to control the flow of current or the application of voltage to the load. Many types of circuits are in use. In its basic form the magnetic amplifier is often called a SATURABLE REACTOR. It is constructed of two or more coils wound on a common core made of magnetic material. A d-c control voltage is applied to one of the windings. The resulting current causes magnetic saturation of the core and this serves to modify the REACTANCE of the second winding. REACTANCE is part of the impedance of an a-c circuit which is due to capacitance or inductance or both. The second coil, which is connected in the a-c load circuit, varies the current in accordance with

changes made in the control-circuit voltage. In more complex magnetic circuits, dry disc rectifiers are often employed and the control signal may be either d-c or a properly phased a-c voltage.

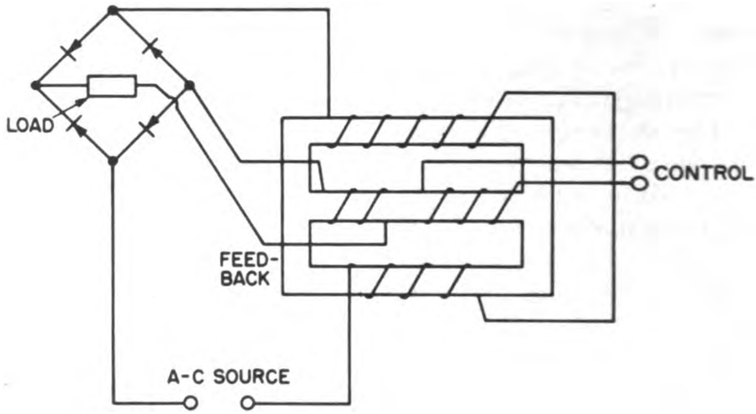


Figure 12–19.—Saturable reactor.

Figure 12–19 shows a pair of saturable reactors connected to control an a-c induction motor. The main field of the motor is connected to the line in the usual manner. One end of the control field winding is connected to the center tap of a transformer fed by the line. The other end is connected through a pair of saturable reactors to both ends of the transformer. When no d-c flows through either reactor, the control field is not energized. Assume d-c flows through one reactor. The INDUCTANCE of the reactor is decreased as a result of this d-c flow. INDUCTANCE is the rate of increase of magnetic linkage with an increase of current. As a result of the decrease of inductance of one of the reactors, the control field is connected to one end of the transformer through a high impedance and to the other end through a low impedance. The control field is, therefore, energized in one direction or the other, and forward or reverse torque is developed by the motor. The d-c through the reactors

is supplied by a pair of thyratrons. These tubes receive an a-c error voltage and are connected to an a-c plate supply.

Note that the a-c for the motor and the reactors may be of one frequency and the error voltage and the thyratron plate supply may be of another frequency. Vacuum tubes may be used instead of the thyratrons if the error signal is a-c. If the error signal is d-c, the signal might possibly be used directly to saturate the reactors, or a d-c amplifier may be used when the signal is not strong enough to produce the desired degree of saturation.

A magnetic amplifier uses a saturable reactor. This reactor has an extra winding that carries a direct current called a BIAS current. For purposes of illustration we shall consider the P-1 autopilot system which employs a magnetic amplifier in the servomechanism system of the autopilot. These amplifiers are motor controlling devices in this case and control the motors associated with the rudder control channel of the system schematically shown in figure 12-20.

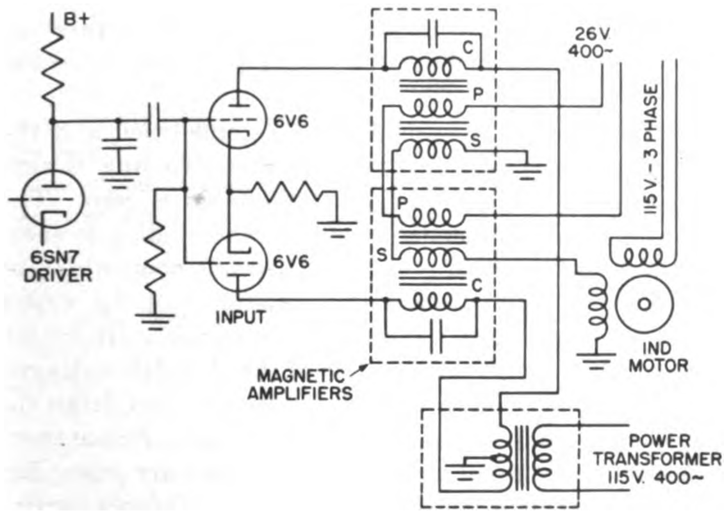


Figure 12-20.—Magnetic amplifier.

In the figure, a separate amplifier unit is provided for each of the two 6V6 tubes. Each amplifier contains a primary, secondary and control winding. The control windings (C) of the two units are connected between the plates of the 6V6 tubes and in series with the secondary of a power transformer. The primary windings (P) are connected in series and are excited from a 400-cycle outside power source. The secondary windings (S) are also in series and are connected to the variable-phase winding of a low-inertia motor in the rudder servo unit.

The plate voltage variations of the 6V6 tubes are out of phase being derived from opposite ends of the transformer winding. Hence, only one tube can conduct at a time, as determined by the polarity relation between the plate voltage and the a-c signal applied to the grid of the driver tube. When current flows in either plate circuit, the control winding in the associated magnetic amplifier is energized and saturates the core. This condition prevents normal transformer action and limits or cuts off entirely the induced voltage heretofore appearing in the secondary winding (S). The voltage induced in the secondary not under saturation then excites the variable-phase winding of the induction motor.

The secondaries are wound in phase opposition and the net voltage induced in the variable-phase winding is zero when the input signal to the control tubes is zero. The motor accelerates when the variable-phase winding is energized and the direction or rotation depends upon which of the tubes supplies the excitation. Reversal of the motor occurs when the phase of the input grid signal reverses with respect to the instantaneous values of the 6V6 plate voltages.

In the autopilot application, the output is taken from the secondary winding of a saturable transformer. Hence there is no induced output voltage present when the core flux reaches a maximum value since in that condition the flux variation becomes negligible.

Pick-off

PICK-OFFS were mentioned briefly in chapter 4 of this text. We shall examine them more closely in this section. What is a pick-off? By definition it is a device which produces a useful signal from the intelligence developed by a gyro, rate gyro, accelerometer, control surface and other missile components. The signal must meet the requirements of the servo system it is serving as to phase, amplitude, and loading effect.

The pick-off must have direction sense; that is, it must be able to distinguish the direction of displacement and produce a signal indicative of this displacement. In electrical pick-offs this is done by phase and/or polarity differences. The electrical pick-offs normally used in control systems are synchros, potentiometers, reluctance and capacity types. Each of these has its own particular application. The synchron system was previously explained in chapter 4.

Potentiometer or resistive pick-offs used in servo systems consist of wire wound resistors and movable sliding contacts. This type of pick-off should be considered as one supplying a varying voltage output rather than one supplying a varying resistance. The reason for this is that a voltage is applied to the potentiometer and some portion of this voltage is picked off and appears as the output. This is illustrated by figure 12–21. This basic bridge circuit is supplied with some value of voltage ($E_{APPLIED}$). There is no output developed when the potentiometer AB is arranged in the bridge

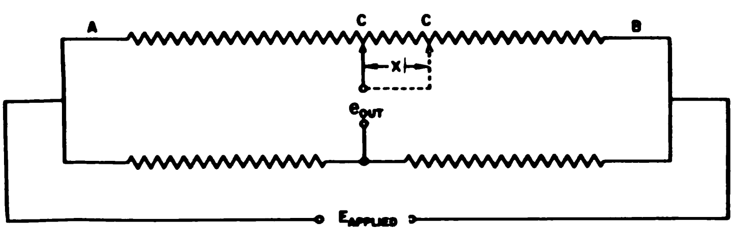


Figure 12–21.—Basic bridge network.

circuit as shown, and the wiper arm is set to position C so that the resistance is equal on both sides of the wiper arm. An output is developed when the wiper is at position C′, having been displaced a distance x from the mid position. The output voltage in this case is directly proportional to the displacement.

The potentiometer as shown in figure 12–22 does not give a smooth output. If you will notice in the figure the potentiometer is made up of a series of turns around a resistance card; this card if formed into an arc or approximately 360° with a space between the ends. The slider or wiper is free

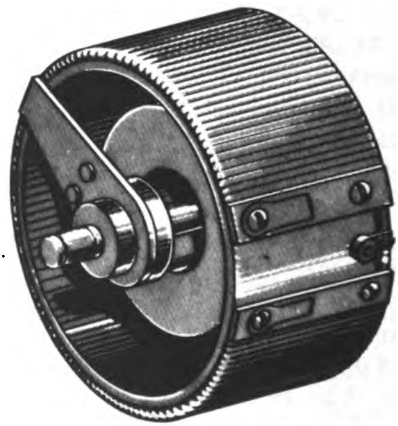


Figure 12–22.—Wire wound potentiometer.

to rotate through 360° making contact with the resistance wire through the entire 360° with exception of the spacer arc at the ends of the card. The voltages from this device vary as a result of the voltage differences between adjacent turns of wire on the potentiometer.

In order to give a smoother output, a HELIPOT may be used. This is a potentiometer wound in the form of a helix. The resolution or ability to distinguish small changes is improved by using this type of potentiometer. In this type

of pick-off the slider cannot rotate through 360° and come back to the point of origin. That is to say it goes from minimum to maximum level, and the direction of rotation must be reversed in order to bring the slider back to the minimum level.

A MICROSYN, as illustrated in figure 12–23, may occasionally be used as an induction potentiometer. The major

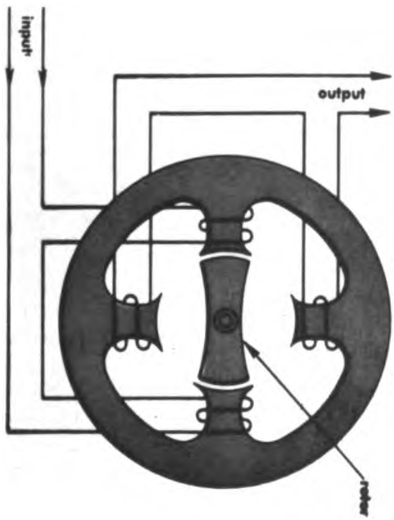


Figure 12–23.—Microsyn.

advantage of this device is that there are no electrical connections to the rotor and hence no brushes with a resultant decrease in friction losses. The magnetic field of the input windings magnetizes the iron rotor. The magnetic field of the rotor in turn induces a voltage in the output windings, unless of course the rotor is in the zero position. Over a limited range the output voltage is proportional to the displacement of the rotor. The microsyn requires the use of alternating current.

VARIABLE RELUCTANCE pick-offs are used with sensing equipment which has small displacement values or oscillatory movements. They give the largest output per unit displacement with a minimum of loading effect. However they require stable oscillators, thus making space and weight demands on the missile.

Since the reluctance pick-offs require an oscillating voltage for their operation, they can be classed by the method used to supply this voltage. An internally oscillated pick-off is illustrated in figure 12–24. The figure shows a rate

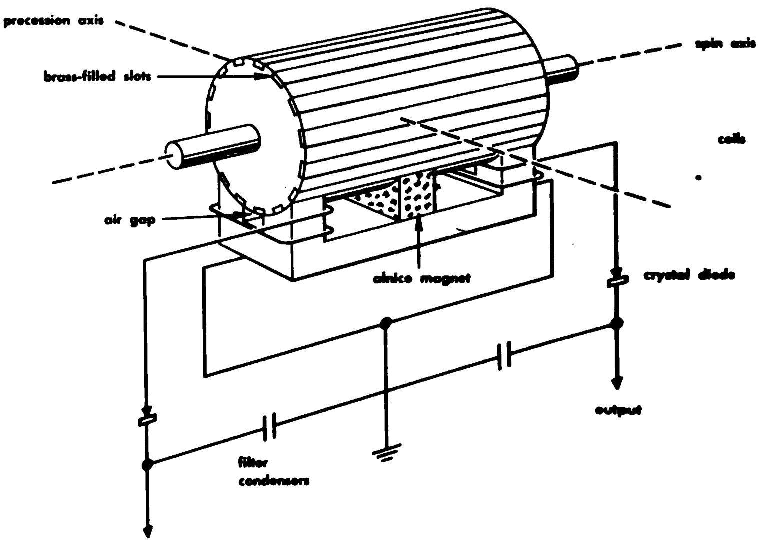


Figure 12–24.—Internally operated reluctance pick-off.

gyro rotor and its reluctance pick-off. The pick-off consists of the E-shaped metal mass with coils wound around its ends and a permanent magnet located in the center. The gyro rotor is a ferrous material which has been slotted and the slots filled with brass to restore the lost weight.

The magnetic force set up by the magnet causes a flux to flow through each end of the pick-off mass, through the

gyro rotor, and back into the magnet. The gyro rotation causes regular variations in the reluctance of the flux paths as the brass and ferrous metals pass over the end pieces. This causes a regular variation in flux density to be established in an a-c voltage in the coils. However, the voltages in the coils cancel each other out.

When the gyro precesses, the air gaps at each end vary oppositely in proportion to the acceleration and cause different voltages to be induced in the coils. The difference in these two voltages is then proportional to acceleration and, after being rectified, the difference is the signal voltage. The output sense shows up here as a difference in polarity.

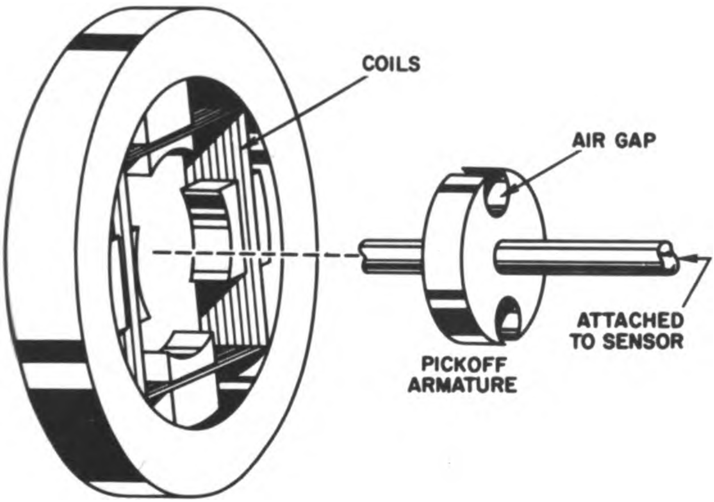


Figure 12–25.—Externally operated reluctance pick-off.

Another type of reluctance pick-off is shown in figure 12–25. It is made up of a stator containing two pairs of coils mounted as shown. One pair of coils is supplied with a constant amplitude a-c voltage from a reference oscillator. Voltage is induced in the second pair of coils through a split iron core rotor coupled to the gyroscope gimbal. As the angle between the rotor and the pick-off coil changes due

to variation in the missile attitude, the amplitude of the a-c voltage induced in the pick-off changes proportionally; the phase of the voltage induced differs by 180°, dependent upon the direction of the missile attitude change from the zero position.

A VARIABLE CAPACITY pick-off makes use of a movable capacitor plate located between two fixed plates. Upon movement of the center plate by the sensing element, the capacities of the two capacitors are varied and their outputs when wired into the appropriate circuit is a useful signal. This type of pick-off is extremely sensitive.

QUIZ

1. The pump in which a definite volume of liquid is delivered for each pumping cycle, regardless of the resistance offered to flow, is the
   a. accumulator pump
   b. actuator pump
   c. positive displacement pump
   d. axial piston air pump

2. A relief valve is installed in the hydraulic line after the pump and before the accumulator to
   a. Prevent losing hydraulic fluid should the pump stop operating
   b. prevent rupture of hydraulic lines or stalling of drive motor in case part of hydraulic system is blocked
   c. maintain correct hydraulic pressure at all times
   d. maintain correct pressure reading on hydraulic pressure gauges

3. The hydraulic system accumulator is used to
   a. help smooth out pressure surges caused by the pulsating output of the positive displacement pump
   b. store excessive hydraulic fluid not used in the system
   c. open the relief valve at a preset value should the pressure output become too great
   d. remove air from the system that would cause flutter in the missile control surface

4. The purpose of a hydraulic actuator is to
   a. move the needle on the hydraulic gauge as an indication that the hydraulic system is operating correctly
   b. turn the hydraulic pump at the correct rpm to maintain even pressure throughout the system
   c. connect the cylinder and exhaust ports for correct actuation of control surfaces
   d. transform fluid pressure into mechanical force necessary for moving a control device

5. The pressure output of the hydraulic pump is dependent upon
   a. the amount of hydraulic fluid in the pump
   b. speed of the drive motor
   c. proper actuation of the pressure relief valve
   d. size of the drive motor

6. The valve located between the reservoir and hydraulic pump and used to prevent the pump from exerting a reverse pressure on the pump is a
   a. check valve
   b. poppet valve
   c. pressure relief valve
   d. needle valve

7. The most effective type filter used in missile hydraulic systems is a
   a. Cuno type
   b. self sealing vacuum type
   c. micronic type
   d. paper bellows type

8. The designs of absorption type filters are, in general, determined by
   a. the temperature of the fluid passing through for filtering
   b. the viscosity of the fluid
   c. the pressure of the fluid
   d. the amount of fluid in gallons per minute passing through for filtering

9. What are the four general types of hydraulic seals?

10. In all hydraulic systems operating under high pressure, leather breakup rings are used
   a. to protect "O" ring seals from being extruded or pushed out of place
   b. only on non-moving parts
   c. with metallic seals, commonly known as crash washers, as air valve seats on accumulators
   d. with C-ring packing to prevent external leakage in stationary and moving parts

11. The purpose of the restrictor is to
   a. limit the rate of flow of fluid to one direction only
   b. limit the rate of flow of fluid through the orifice
   c. determine rate of flow of fluid through the orifice
   d. determine the correct adjustment of the needle valve

12. All gases expand and contract to the same extent under the same change of temperature
   a. provided the pressure is changed a proportional amount
   b. if there is no change in pressure
   c. if the volume of gas is inversely proportional to its absolute temperature, pressure being constant
   d. according to Boyle's law

13. The volume of a gas increases as the temperature increases; however if its volume is held constant as its temperature is increased,
    a. its pressure would decrease
    b. its pressure would increase
    c. its pressure would remain the same
14. Electrical energy, by means of magnetic force, can produce mechanical motion in an electric actuator by means of a solenoid or motor. Which of the following statements is true?
    a. The solenoid, due to its electrical strength, can cause airfoil movement by itself.
    b. A small motor running at high speed can move the airfoils directly.
    c. A gear train in conjunction with a motor is necessary for airfoil actuation.
15. The main advantage of the all-electric system of control is
    a. its small size in comparison to other systems
    b. that it requires only one power source thus reducing the overall weight of the missile
    c. that there is no lag in control surface response due to inertia of the electric motor
    d. its high sensitivity and small oscillations
16. Since a motor which operates a control surface is coupled through a gear train to the control surface, the control surface movement is
    a. either all the way up or all the way down
    b. inversely proportional to the speed of the motor and proportional to signal strength
    c. proportional to the speed of the motor and therefore the signal strength
    d. independent of the speed of the motor
17. The effects of inertia when starting and stopping a variable speed motor can be reduced by
    a. installing capacitors across the power supply leads
    b. using a drive motor which runs continuously and at variable speeds
    c. using a drive motor which runs intermittently and at variable speeds
    d. using a drive motor which runs continuously and maintains rather uniform speeds
18. Magnetic amplifiers are devices which control the degree of magnetization in the core of a coil in order to
    a. control the plate voltage on the rectifier tube in the power supply

b. prevent magnetic saturation of the core
c. keep a steady d-c control voltage applied to one of the core windings
d. controls the flow of current or application of voltage to a load

19. The major advantage of a microsyn is
a. that there are no electrical connections to the rotor and hence no brushes with a resultant decrease in friction losses
b. over a limited range the output voltage is proportional to the displacement of the rotor
c. the microsyn doesn't require the use of alternating currents
d. its small size and dependability

20. A variable capacity pick-off makes use of a
a. fixed capacitor and a variable inductance
b. movable capacitor plate located between two fixed plates.
c. a movable coil oriented in a magnetic field
d. a movable coil located between two fixed plates

CHAPTER 13

INTRODUCTION TO MISSILE TELEMETERING

When any new device is being developed, it must be given an exhaustive series of tests which reveal its operating characteristics and serve as the basis of evaluation. With most devices the conditions are such that one or more human observers can study the action close at hand and measure numerous quantities while the apparatus is in operation. A new type of airplane is repeatedly flown under all sorts of conditions by a skilled test pilot. And each flight provides first-hand information as well as information derived from instruments and recorded for later study. A new engine for an automobile is first placed on a test stand; it is run for long periods of time, during which it is observed closely and numerous measurements are made to determine its capabilities. Later it can be installed in an automobile and tested for as long as may be required.

One of the important problems in missile development is that the missile cannot be flight tested by a human pilot. Also, in most cases, once the missile is fired it is gone forever, being reduced to junk upon striking the earth or sinking beneath the surface when it comes down at sea. (In the development of large, surface-launched missiles, the best vehicle is sometimes equipped with landing gear and can be brought to earth without destruction; but this is rarely, if ever, the case with smaller, air-launched weapons.) As a result, the missile designers have developed other methods of deriving test data pertaining to these single-flight birds.

INITIAL TESTING

The initial tests of a new missile system are often made on a flight simulator, which is a special type of computer. The performance characteristics of the individual components of the proposed missile are set into the simulator in the form of dial settings (or equivalents); and the results come out as curves traced on graph paper. In this way, a simulated "flight" takes only a few seconds and costs almost nothing compared with an actual flight. After a simulated flight, adjustments can be made to determine whether the performance can be improved by altering the control surfaces, by changes in the control system, and so on. If all the necessary information had to be derived by actual test, the expense would be prohibitive since the testing of the numerous individual sections or components by actual flight would cost a new missile for each separate item. After flight simulation is completed, the new missile can then be constructed in accordance with the best results obtained from the simulator, and actual flight testing can begin.

Electronic and mechanical components react differently under the various conditions of missile operation. Results gained when testing the missile on the ground may be very different from the results obtained when firing the missile to an altitude of 30,000 feet. Temperatures, pressures, and accelerations encountered at the higher altitudes may change the operation of the missile materially. In order that the operation of the overall system might be known under actual firing conditions, specialized TELEMETERING equipment was designed and produced for missile use.

REQUIREMENTS OF MISSILE TELEMETERING EQUIPMENT

Telemetering is a word of Greek origin, meaning "measurement from a distance." Both the term and the processes it signifies have been used in industry and elsewhere for a number of years. In many industrial applications, various kinds of data are often transmitted over wire links. Radio telemetering has also been in use since the mid thirties, especially for sending weather data gathered by balloon-

supported instruments and emitted by radio transmitters. The principal element of this kind of equipment is called RADIOSONDE, which is still one of the most important tools used by the aerographer, particularly in that part of his job which pertains to weather forecasting.

Like radiosonde, missile telemetering systems operate by radio. These systems permit the measurement and study of missile performance from a remote point. They are usually designed to carry out the following major processes or functions: conversion of the quantities to be studied into electrical signals; transmission of the signals from the missile transmitter to a receiving station, located either in an airplane or on the ground; reception of the signals and decoding of the various data; presentation of the data in visual form and recording of the data in permanent records.

Since a great amount of varied information is required during the separate stages of a missile test program, the primary requirement of a missile telemetering system is the ability to gather, transmit, and process a large amount of data in a short period of time. The types of information usually required include (1) changes in attitude, in pitch, yaw, and roll; (2) airspeed; (3) altitude; (4) various components of acceleration; (5) ambient conditions such as pressure, temperature, and humidity; (6) operation of the control equipment, such as the receiver, autopilot, hydraulic servos, the displacement of the control surfaces, and the operation of the homing or target-seeking equipment; (7) propulsion information, such as temperature and pressure of the rocket assembly, (8) ordnance functions, such as fuze-arming time; (9) the operation of the electrical system; and (10) data required for the coordinated operation of the telemetering equipment itself, such as reference voltages used for calibration, time marks, and signals which permit the synchronizing of the data recorded by several receivers located along the flight path.

The receiving equipment is designed to accept all the information provided by the transmitter in the missile, to demodulate the separate signal channels, and to decode the

resultants for presentation to the recording section. Proper recording of the information derived is the final step in the process. The permanent records are made by various means: by magnetic-tape recorders, by pen recording equipment, and on photographic film. In photographic recording, both movie and still cameras are employed.

Radio transmitting and receiving equipment of the frequency-modulated and of the pulse types are used in missile telemetering. The principal features of the former type are considered first, the following section being devoted to a description of the F–M/F–M system.

THE F–M/F–M TELEMETERING SYSTEM

The F–M/F–M telemetering system employs the basic techniques of frequency modulation and can be used to transmit simultaneously large quantities of missile data. The missile-borne portion of the system includes a number of frequency-modulated oscillators, the combined outputs of which are fed into a frequency-modulated, very high-frequency transmitter. Each separate oscillator produces a signal called a SUBCARRIER the frequency of which is modulated in accordance with one of the missile functions to be monitored. The number of subcarrier oscillators (and hence, the number of missile functions telemetered) may be as high as 18.

The essential elements of both the missile equipment and the receiving section of the overall system are indicated in the block diagram in figure 13–1. In (A) of the figure, representing the components carried in the missile, only two subcarrier oscillators are shown for simplicity; however, in most installations the number of oscillators included is much greater. The subcarrier oscillators operate on different center frequencies so that each provides a separate signal channel. Each oscillator is frequency modulated by means of a pickup device, called a TRANSDUCER. One transducer is used for each signal channel, the function of the device being to convert the quantity to be measured into a form suitable for modulating the associated oscillator.

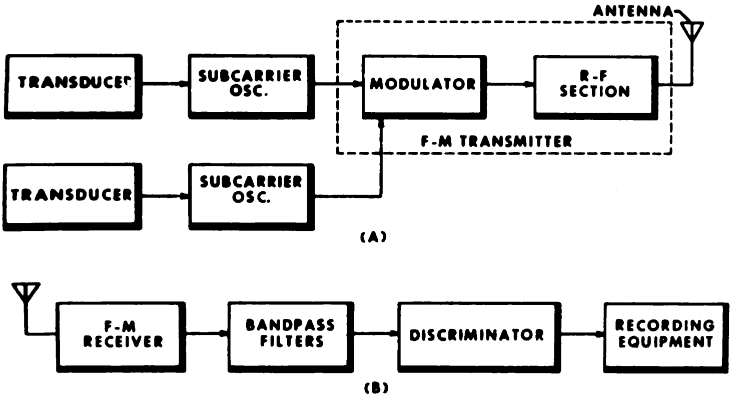


Figure 13–1.—Simplified block diagram of an F–M/F–M system.

The various subcarrier signals are applied to the MODULATOR which in turn modulates the output of a crystal controlled oscillator in the radio-frequency section of the transmitter. The resulting signal is multiplied in frequency up to the value assigned for the carrier wave and is then applied to the antenna for transmission to the receiving station. The carrier frequencies allocated for telemetering purposes are included in a band ranging from 216 megacycles to 235 megacycles.

As indicated in figure 13–1B, the transmitted carrier wave is picked up at the receiving station by an f-m RECEIVER. After considerable amplification, the subcarrier signals are detected and then separated into separate channels by means of BANDPASS FILTERS. Each signal channel contains a DISCRIMINATOR which converts the frequency variations present in the subcarrier into audio-frequency variations, the amplitudes of which are proportional to the value of the corresponding quantity measured in the missile. The a-f signals developed in the various signal channels are then recorded for data reduction and evaluation.

Subcarrier Frequencies

The subcarrier oscillators used in the telemetering transmitter generate comparatively low-frequency signals situated in the bands given in table 13–1. Eighteen standard bands

TABLE 13–1.—SUBCARRIER OSCILLATOR FREQUENCY BANDS

Band	Lower limit (c. p. s.)	Center frequency (c. p. s.)	Upper limit (c. p. s.)	Typical intelligence frequency (c. p. s.)	Maximum intelligence frequency (c. p. s.)	Frequency deviation (percent)
1	370	400	430	6	30	±7. 5
2	518	560	602	8	42	±7. 5
3	675	730	785	11	55	±7. 5
4	888	960	1032	14	72	±7. 5
5	1202	1300	1398	20	98	±7. 5
6	1572	1700	1828	25	128	±7. 5
7	2127	2300	2473	35	173	±7. 5
8	2775	3000	3225	45	225	±7. 5
9	3607	3900	4193	60	293	±7. 5
10	4995	5400	5805	80	405	±7. 5
11	6799	7350	7901	110	551	±7. 5
12	9712	10, 500	11, 288	160	788	±7. 5
13	13, 415	14, 500	15, 588	220	1088	±7. 5
14	20, 350	22, 000	23, 650	330	1650	±7. 5
15	27, 750	30, 000	32, 250	450	2250	±7. 5
16	37, 000	40, 000	43, 000	600	3000	±7. 5
17	48, 560	52, 500	56, 440	790	3940	±7. 5
18	64, 750	70, 000	75, 250	1050	5250	±7. 5

OPTIONAL BANDS						
A	18, 700	22, 000	25, 300	660	3300	±15
B	25, 500	30, 000	34, 500	900	4500	±15
C	34, 000	40, 000	46, 000	1200	6000	±15
D	44, 620	52, 500	60, 380	1600	7880	±15
E	59, 500	70, 000	80, 500	2100	10, 500	±15

are allocated for telemetering subcarrier use. In addition, five optional bands are provided for special purposes which require a greater value of allowable frequency deviation than that established for the standard bands. As indicated in the table, the center frequencies about which the subcarriers are modulated range from 400 cycles to 70 kilocycles. The permissible frequency deviation in the standard bands is plus or minus 7.5 percent and 15 percent in the optional bands. The intelligence frequencies, which represent the quantities to be telemetered, range in typical value from 6 to 30 c. p. s. in the lowest band and from 2,100 to 10,500 c. p. s. in the highest.

TRANSMITTING EQUIPMENT

Input Transducers

As indicated in figure 13–1, the telemetering process originates in the airborne equipment where the missile functions are detected and measured by the input transducers. By definition, a transducer is any device which is used to convert energy in one system into energy of a form suitable for use in another system. In missile telemetering applications, the input transducers commonly employed include VARIABLE-RELUCTANCE, VARIABLE-INDUCTANCE, and VARIABLE-RESISTANCE units. Because of the required compactness of missile equipment, the transducers are usually specially designed for the particular system and are usually mounted as integral parts of the subscriber oscillator circuitry. As parts of the subcarrier oscillators in an F–M/F–M system, they operate by converting the missile functions into audio-frequency signals which modulate the output of the oscillator in frequency.

An example of the variable-reluctance transducer is the accelerometer, the theory of which is discussed in chapter 11 of this course. In addition to acceleration, missile quantities frequently measured by variable-reluctance units include ambient pressure, velocity, motions of servo linkages, and positions of control surfaces.

A typical member of the variable-inductance class of transducers is the saturable reactor, which is often used to measure missile quantities such as critical power-supply voltages or the currents flowing in certain tubes in the electronic circuits. The saturable reactor designed for use as a transducer consists of a laminated, magnetically saturable core upon which is wound an inductance coil, a control coil, and a biasing coil. As the current in the control winding is changed, the magnetization of the core changes with the result that the inductance of the principal coil is varied correspondingly. When connected so as to form a part of the tank circuit of an oscillator, the inductance coil by its variations can control, within limits, the frequency of the oscillator. The saturable reactor is a power-consuming device and is not desirable for measuring missile functions represented by voltages which are developed in high-impedance sources such as AGC voltages in missile receivers.

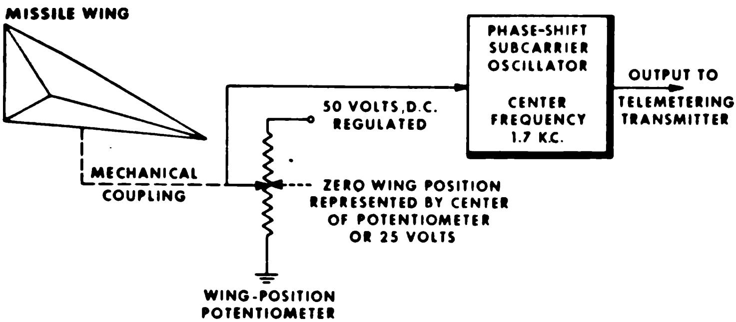


Figure 13–2.—Wing-position telemetering device.

A typical example of a variable-resistance telemetering pickup is shown in figure 13–2. The potentiometer, serving as the transducer, and the oscillator which it controls, make up a subcarrier signal channel for monitoring the position of a missile wing. The slider of the potentiometer is mechanically coupled to the wing so that a variable voltage is picked off and applied to a control tube which forms part

of the oscillator circuit. For each position of the wing there is a corresponding value of voltage applied to the control tube, which adjusts the output frequency of the circuit in accordance with the instantaneous positions of the wing.

Impressed across the potentiometer (fig. 13–2) is a regulated, d-c potential of 50 volts. When the wing is in the center (zero) position, the potentiometer arm is also at the center position where it applies 25 volts to the control tube. This voltage serves as a bias for the control tube which causes the output signal of the oscillator to be situated at 1.7 kilocycles, the center value of band 6 (table 13–1). As the wing moves in response to the missile control system, the slider of the potentiometer moves also and readjusts the control tube bias. As a result, the output frequency is varied within the limits of 1,572 and 1,828 c.p.s.

The oscillator employed in the system shown in figure 13–2 is of the phase-shift type, a basic circuit often used in telemetering applications because of the ease with which its frequency can be varied by means of a biasing voltage. The operation of the circuit is explained in detail in the following section.

Subcarrier Oscillators

Two basic circuits are widely used as subcarrier oscillators in f-m telemetering systems. One is the phase-shift circuit mentioned in the preceding section; the other is the Hartley oscillator, the theory of which is discussed in chapter 7 of *Basic Electronics*, NavPers 10087. The application of both types in a representative missile telemetering transmitter, together with typical frequency values employed in the two types, is indicated in the block diagram shown in figure 13–3. The components shown comprise a transmitting system capable of providing 10-channel telemetering.

THE HARTLEY CIRCUIT.—The Hartley oscillator, when used as a subcarrier generator, is most frequently equipped with a variable-reluctance transducer. An example of this

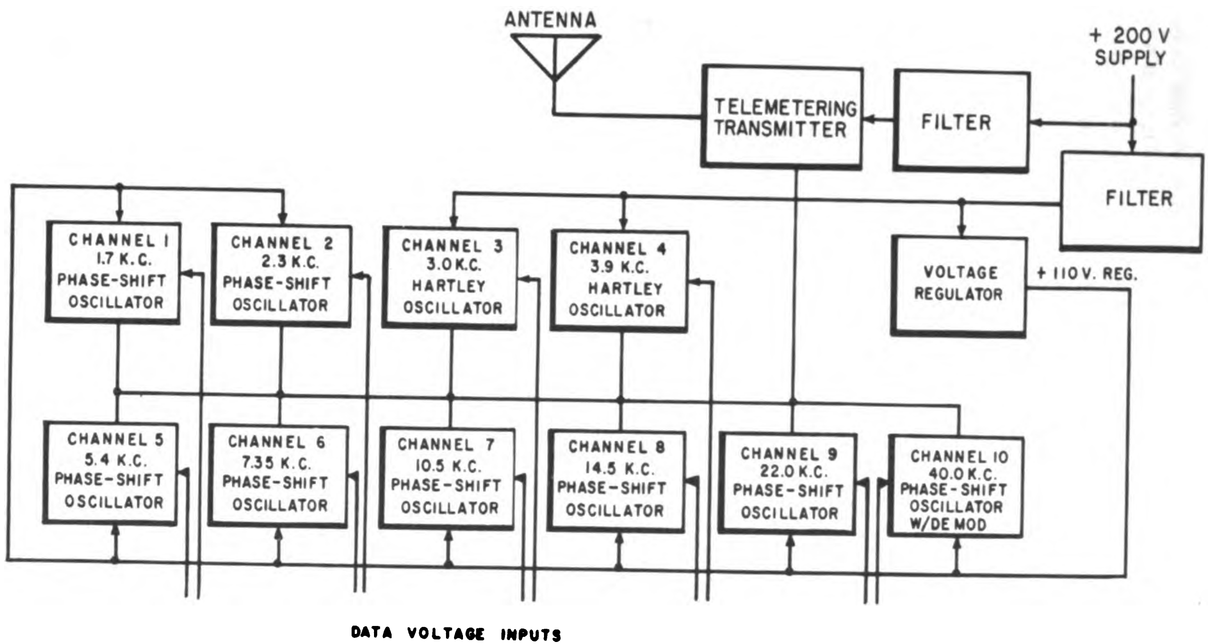


Figure 13—3.—Block diagram of 10-channel transmitting equipment.

arrangement is shown in schematic form in figure 13-4 in which the transducer is an accelerometer. In such applications the accelerometer is usually of the E-coil type and is connected as the inductance portion of the tuning, or tank, circuit of the oscillator.

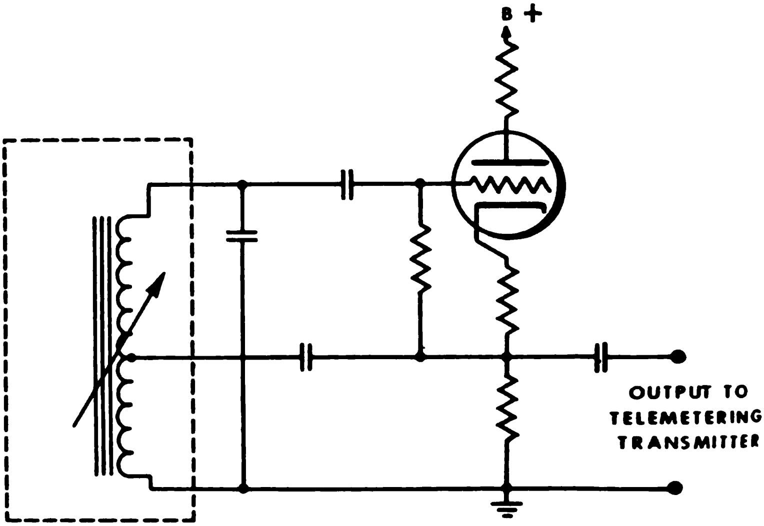


Figure 13-4.—Hartley oscillator with accelerometer transducer.

The circuit shown (fig. 13-4) might be employed for telemetering the values of one component of missile acceleration. The E-coil and mu-metal pad of the accelerometer form a variable-reluctance pickoff, the sensitive element of which responds to acceleration in one of the missile axes. Changes in the air gap of the accelerometer result in corresponding changes in the reluctance of the magnetic path, with a resulting change in the inductance of the winding connected in the oscillator tuning circuit. In this way the output of the oscillator is frequency modulated by amounts proportional to the missile accelerations to which the transducer is sensitive.

Phase-Shift Oscillators.—The operation of the phase-shift oscillator is based on the following facts concerning electronic amplifiers. If the output voltage of a single-stage amplifier is fed back to the input through a frequency-sensitive network, the circuit will oscillate. The frequency of oscillation is that value at which the network shifts the phase of the feedback voltage by 180 electrical degrees with respect to the output voltage. The oscillation will be sustained if the gain of the amplifier is great enough to overcome the losses of the coupling network.

A simplified schematic diagram of an oscillator which operates on these principles is shown in (A) of figure 13–5. The circuit contains a control tube to provide a means of varying the frequency of the output signal over a range sufficiently wide for f-m telemetering; and in this form, the oscillator is suitable for use in a subcarrier channel of an F-M/F-M system. A vector diagram illustrating the phase relations upon which frequency control depends is shown in (B) of the figure.

The oscillator employs a three-section, *R-C* network to provide the phase displacement necessary for oscillation. The network is composed of the sections R_1-C_1, R_2-C_2, and R_3-C_3. These, together with *V*–2, (a cathode-follower tube), make up the feedback loop through which voltage variations are coupled from the plate of *V*–1, the oscillator tube, back to the grid. *V*–2 serves to match the impedance of the network to the oscillator tube and to couple the signal to the control tube, *V*–3. The cathode-follower stage also provides a convenient element from which the output signal of the circuit can be taken. When placed in operation, the circuit generates oscillations at the frequency at which the *R-C* network provides the necessary 180-degree phase shift.

The control tube, *V*–3, varies the frequency of the output signal in accordance with the data voltage applied to the grid. The plate circuit of the tube is a part of the input section of the *R-C* network; and the tube action determines the phase shift produced in this section, thus governing the

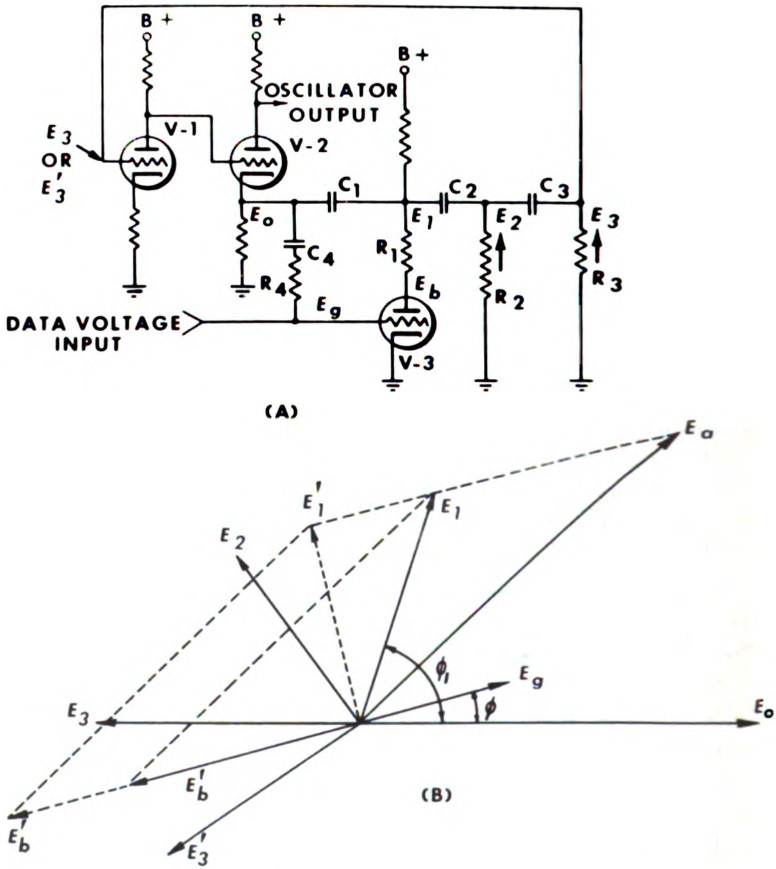


Figure 13–5.—(A) Schematic diagram of a phase-shift oscillator; (B) vector diagram.

frequency at which the circuit can oscillate. The change in phase angle introduced by the control tube is shown in (B) of figure 13–5. This method of representing phase relationships is based on the discussions given in chapters 12 and 13, *Basic Electricity*, NavPers 10086.

The vector labeled E_o symbolizes the voltage at the output of the cathode follower. This voltage is coupled both to the *R-C* network and also to the grid of the control tube through the combination R_4-C_4 which produce a phase shift of ϕ degrees (fig. 13–5). The output, or plate voltage, of *V*–3 is an amplified voltage, E_b, which is 180 degrees out of phase with the grid voltage. The voltage, E_a, appears across R_1 and results from coupling the output of the cathode follower through C_1. The vector sum of E_a and E_o is E_1, the resultant voltage appearing at the first *R-C* section. This voltage produces voltages E_2 and E_3 at the second and third sections of the network, respectively. The voltage E_3 is applied to the input of the oscillator tube in the proper phase relation to cause oscillation.

Any increase in the data voltage causes the plate voltage of *V*–3 to change from E_b to E'_b as shown in (B) of figure 13–5. The voltage E_a remains substantially constant so that E_1 now shifts to E'_1. Voltages E_2 and E_3 depend upon E_1 and shift in phase in accordance with it. The voltage now fed back to the grid of the oscillator tube is no longer in the proper phase to sustain oscillation at the previous frequency. As a result, the output signal is changed to a new frequency at which the total phase shift of the network is once more 180 degrees. The new frequency is then a measure of the data signal voltage applied to the control tube.

The Telemetering Transmitter

As indicated in figure 13–3, the output signals from all the subcarrier oscillators in the F-M/F-M system are fed to a common point, the input of the telemetering transmitter. The components of a transmitter of the type employed

in the system are shown in a block diagram in figure 13–6. The carrier frequencies of telemetering transmitters are situated in the band extending from 216 to 235 megacycles. As indicated in the figure, the signal from which the carrier is developed originates in a crystal oscillator operating at a comparatively low frequency, a typical value being that shown in the figure, or 6.096 mc. After the output of the crystal oscillator is modulated in frequency by the modulator stage, the resulting voltage, which contains all the

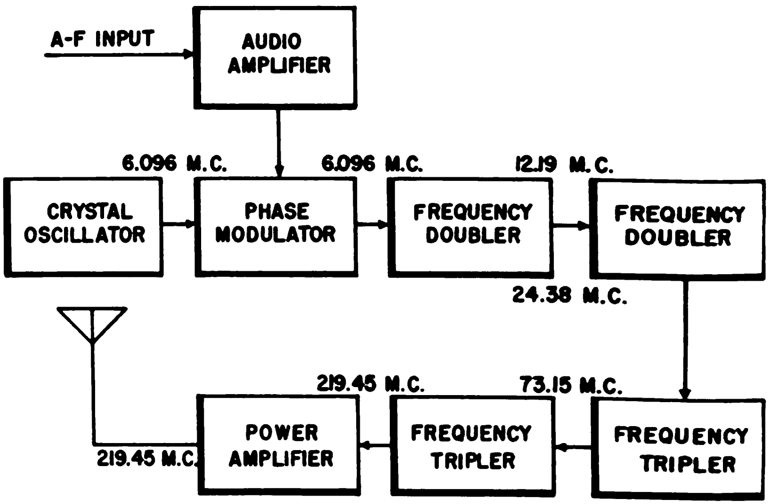


Figure 13–6.—Block diagram of F-M/F-M telemetering transmitter.

telemetering information contributed by the subcarrier channels, is multiplied up to the assigned carrier-frequency value. The frequency multiplication is accomplished by a series of multiplier stages containing both doublers and triplers.

For a discussion of the process of phase modulation employed in the transmitter (fig. 13–6), the trainee is referred

to *Basic Electronics*, NavPers 10087, chapter 8. In the same text he will also find information on an f-m transmitter essentially similar to the telemetering equipment shown above. The discussion in chapter 9 contains a generalized block diagram, a schematic diagram, and detailed description of the operation of the various stages including the function of the frequency multipliers.

Missile telemetering transmitters differ from the f-m equipment explained in the companion text principally in physical form since the missile units must be designed for maximum compactness and light weight. The missile-borne telemetering antenna also differs in construction from conventional f-m antennas because it must conform to the aerodynamics of the missile.

F-M/F-M Receiving Equipment

Figure 13–7 is a block diagram showing the principal components of a 10-channel receiving station that supplements the transmitting equipment described above. The basic units include a specialized antenna system; an f-m receiver; and a group of signal-channel circuits used for separating; detecting, and recording the data contained in the output of the receiver.

The antenna system usually contains a highly directional antenna or combination of antennas controlled by servo units to provide automatic tracking of the missile, thus insuring maximum signal reception. The receiver is generally of the standard f-m type described in chapter 12 of *Basic Electronics*, NavPers 10087, but which is designed to tune in the telemetering bands.

The output of the receiver is a complex, frequency-modulated signal containing all the data impressed on the transmitter carrier wave. In the system shown (fig. 13–7), this includes frequency components representing all the 10 subcarriers, each of which is frequency modulated by the missile data voltages.

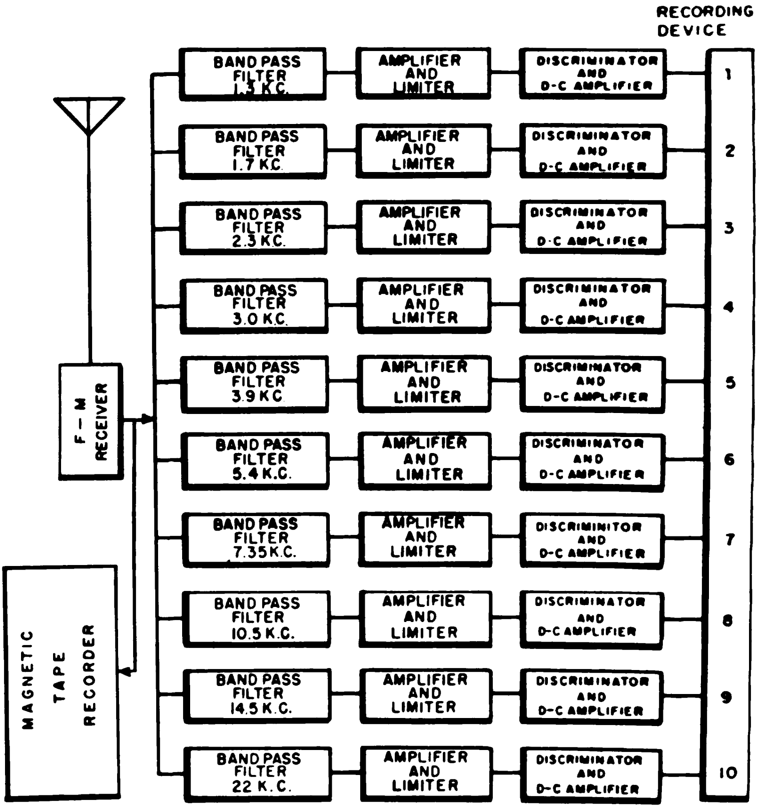


Figure 13–7.—Block diagram of a 10-channel receiving station.

The complex output of the receiver is applied to the inputs of all 10 signal channels. Each channel contains a filter which allows only a narrow band of frequencies to pass. The center frequency of the band accepted by the filter in each channel corresponds in value to one of the subcarrier center frequencies.

After passing through the bandpass circuits, each subcarrier is amplified and then applied to a limiter circuit, which removes any amplitude variations present. The resulting signal, a frequency-modulated wave of constant amplitude, is next applied to a discriminator. In this stage, the frequency variations present in the signal are converted into amplitude variations. Thus, each discriminator output is a d-c voltage, the instantaneous voltage of which is a measure of the missile function monitored in the corresponding transmitter channel. The d-c data voltage are applied to direct-coupled amplifiers to which recording galvanometer or other types of recording devices are connected.

Basic Recording Devices

The data developed by the receiving equipment must be reduced to permanent form in order that it can be studied effectively. This is accomplished by the use of various types of recording instruments. Some of the basic types employed include (1) magnetic-tape recorders, (2) galvanometer oscillographs, and (3) numerous kinds of photosensitive equipment including light-sensitive oscillographs and cameras.

The essential elements of a magnetic recorder are shown in simplified form in (A) of figure 13–8. These recorders are often used in the manner shown in figure 13–7 to collect in very compact form all the data contained in the output of the telemetering receiver. The recording provides a means by which individual channels of data can be recovered at a later time by playing back the tape through the appropriate decoding circuits. The information desired can then be recorded by the use of one of the other types of recorders such as the galvanometer oscillograph.

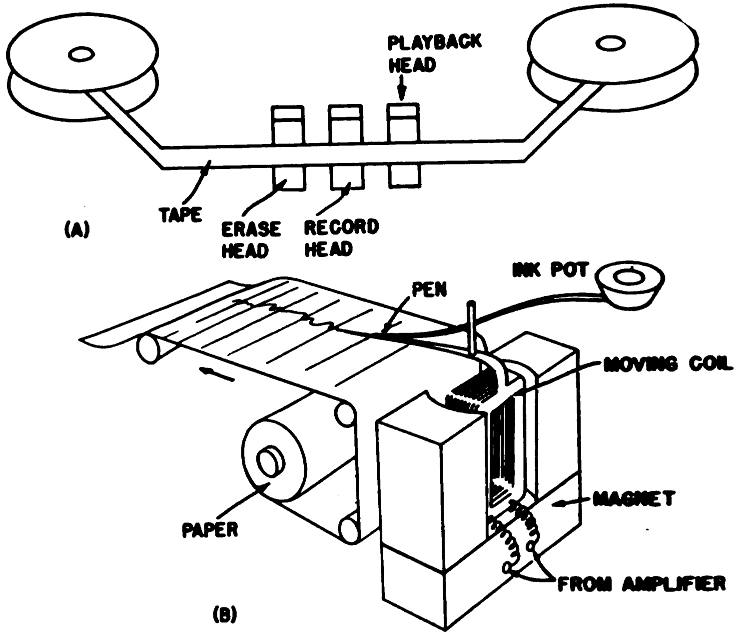


Figure 13–8.—(A) Magnetic-tape recorder; (B) galvanometer oscillograph.

The basic mechanism of the direct writing oscillograph employing a D'Arsonval galvanometer is shown in (B) of figure 13–8. The instrument contains a self-inking pen which is moved across the recording paper by the D'Arsonval assembly. (See chapter 9 of *Basic Electricity* for information concerning this instrument.) The data voltages are applied to the coil of the galvanometer which is mounted in the field of a permanent magnet. The resulting motion deflects the pen laterally by amounts proportional to the voltage applied. The recording paper is moved under the pen at a constant speed by a motor drive so that the pen traces a graph of the varying data values.

A galvanometer oscillograph employing light-sensitive paper and capable of recording several channels simul-

taneously is shown in simplified form in figure 13–9. This recorder contains a number of galvanometer units. To each of the moveable elements a small mirror is attached. Images of a light source are reflected from the mirrors onto a roll of photosensitive paper. The output voltages of the d-c amplifiers in the decoding channels of the receiving equipment are connected to the galvanometers, thereby causing the moveable elements and mirrors to rotate. This action deflects the light images falling on the moving paper and produces traces which represents the variations of the data voltages. The paper is moved at a constant speed by means of a motor.

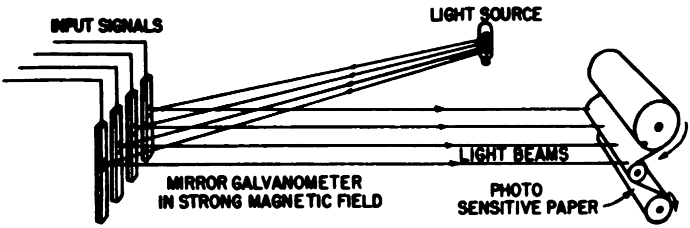


Figure 13–9.—Photosensitive galvanometer recorder.

In some receiving systems, the outputs of the d-c amplifiers are connected to the input circuits of cathode-ray oscilloscopes. And when the sweep voltage of the scope is properly synchronized with the data signals, the traces on the oscilloscope tube represent the variations of the data signal. Cameras are attached to the oscilloscopes to record the traces on film.

PULSE TELEMETERING SYSTEMS

Pulse telemetering systems operate on a time-sharing basis; that is, they transmit separate items of information one at a time and in a regular sequence. The missile data supplied by all the channels are transmitted on the same

carrier wave; but each channel is sampled for comparatively short intervals of time and is permitted to modulate the transmitter only during those intervals. The information to be telemetered is contained in a series of voltage pulses, some characteristic of which is made to vary in turn with each of the missile functions monitored.

There are several basic methods by which voltage pulses can be made to represent accurately the varying quantities measured in the missile. In all these methods, a particular property of a train of pulses is caused to change in accordance with the quantity to be represented. As indicated in figure 13–10, the property may be pulse height, pulse width, or pulse rate. In pulse telemetering, the data voltages provided by the input transducers are selected in a specific order by a commutator, or switching device. Each data voltage is applied to the pulse generating circuits so that it causes a proportional variation in the amplitude, width, or rate of the pulses.

After modification by the data voltages, the pulse series is applied to a modulator which impresses the individual pulses upon the r-f carrier wave radiated by the transmitting antenna. The carrier may be modulated either in frequency or in amplitude.

The P–W–M/F–M System

The pulse-width-modulated/frequency-modulated, or P–W–M/F–M system is one frequently employed in missile telemetry. The pulse series containing the missile information can be represented as in figure 13–11. If N channels are to be monitored, pulses are generated in sets, or sequences, of N square-wave variations; and each set is separated from the set following it by the synchronizing interval, a comparatively long period of time during which no pulses occur.

The input transducers in the missile are designed to produce data voltages ranging in value from 0 to 5 volts. Each datum is used to vary the width of one of the pulses in the series. The series of modified pulses is applied to the modu-

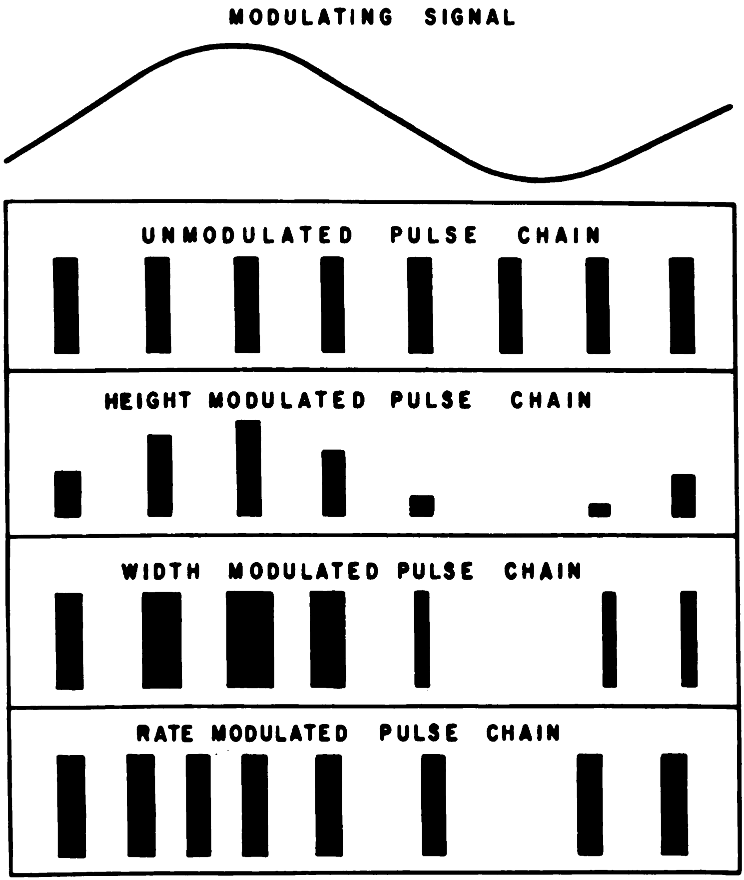


Figure 13–10.—Basic types of pulse modulation.

lator which shifts the frequency of the carrier wave amounts proportional to the widths of each successive pulse. After all the channels have modulated the carrier in this way, the synchronizing interval occurs, separating the last pulse of one sequence from the first of the next, and the sampling process is then repeated.

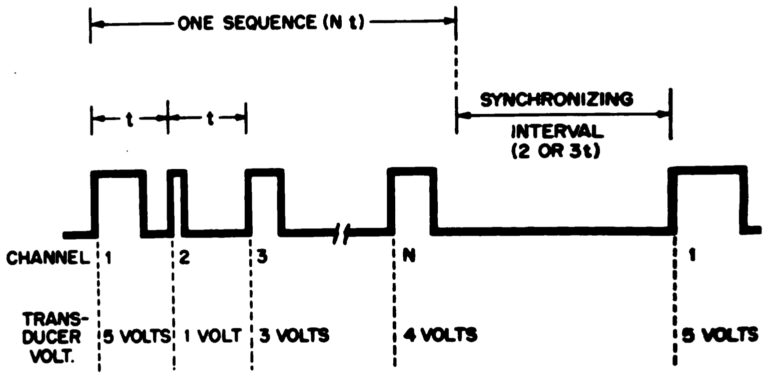


Figure 13–11.—Pulse series for pulse-width telemetering.

Airborne Pulse Equipment.—Pulse-modulated missile information in the form illustrated in figure 13–11 can be transmitted by equipment which is comparatively small in size, light in weight, and simple in design. The major components carried in the missile for gathering, encoding, and transmitting the data are shown in the block diagram in figure 13–12.

In this system, the missile functions are monitored by transducers of the potentiometer type, one of which is provided for each function. A commutator connects the data voltages in sequence to the collector, which contains the pulse generating circuits. The commutator is a mechanical switch in the system illustrated. During each cycle of operation, it applies the full excitation signal, or 5 volts, as well as zero volts to the channel collector. The pulses result-

ing from these inputs are used in calibrating the equipment.

The pulses produced by the collector (fig. 13–12) are modulated in width. The greater the amplitude of the transducer voltage, the wider is the corresponding pulse applied to the modulator. The transmitter is frequency modulated by the modulator in the manner employed in the f-m equipment of the F–M/F–M system.

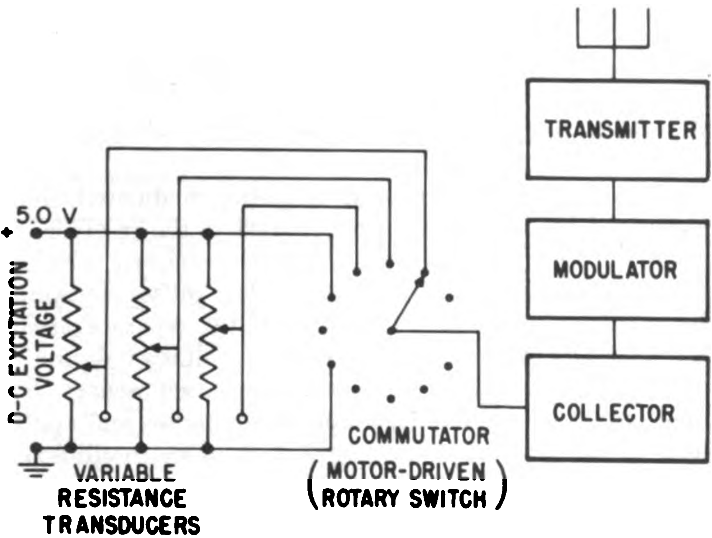


Figure 13–12.—Missile-borne pulse equipment.

RECEIVING EQUIPMENT.—Pulse telemetering receiving equipment contains several major components which are essentially the same as the corresponding units used in the F–M/F–M system. These include the antenna system and the receiver. The principal differences in the two receiving systems are in the circuits which decode the incoming signals. Pulse decoding circuits also differ among themselves in that each must be designed for the specific type of pulse modulation employed. The basic units of a typical P–W–

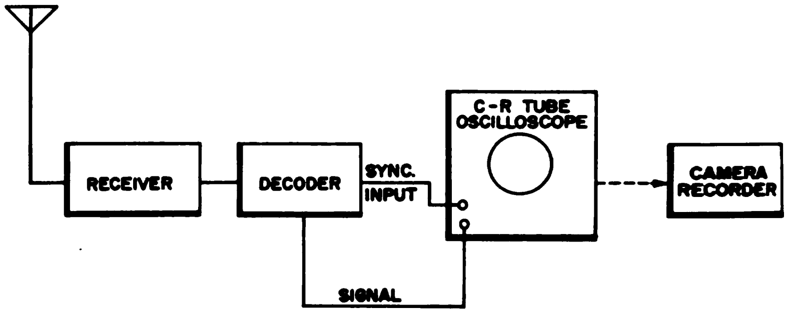


Figure 13–13.—Basic pulse receiving equipment.

M/F-M receiving station are shown in block-diagram form in figure 13–13.

The pulse-width-modulated, frequency-modulated signal is received by the antenna and applied to the receiver, the output of which is taken from a discriminator. The output signals consist of the width-varying pulses containing the missile information. This is fed to two separate circuits in the decoder, one of which developes a voltage used for the horizontal sweep signal of a cathode-ray oscilloscope. The other circuit in the decoder amplifies the pulses and applies them to the vertical deflection circuits in the oscilloscope. The pulse train thus provides the signals used for synchronizing and sweeping the beam in the cathode-ray tube, and the pulse information is displayed as a series of video waveforms occurring in the order in which they were developed in the transmitter unit. The face of the cathode-ray tube is photographed by a movie camera mounted on the scope. The camera thus functions as the recording device in this type of receiving station.

Commutating Devices

Commutating devices are used in pulse telemetering equipment as switches which automatically sample the channel information in the required rate and sequence. Two kinds of

commutators are used: mechanical and electronic. The former are motor-driven, rotary switches; the latter usually consist mainly of a group of multivibrator circuits.

The physical characteristics of a typical mechanical commutator are shown in figure 13–14. The unit is a four-section switch containing 30 contacts per section and equipped with a shorting type contact wiper. The rotor contacts are mounted on the spring-loaded wiper assembly. A pair of contacts are attached to each of two fiber gears driven by a steel worm gear attached to the shaft of a miniature, permanent-magnet motor. The rotor speed is governed by the motor-supply voltage, which can be varied to adjust the rate of sampling.

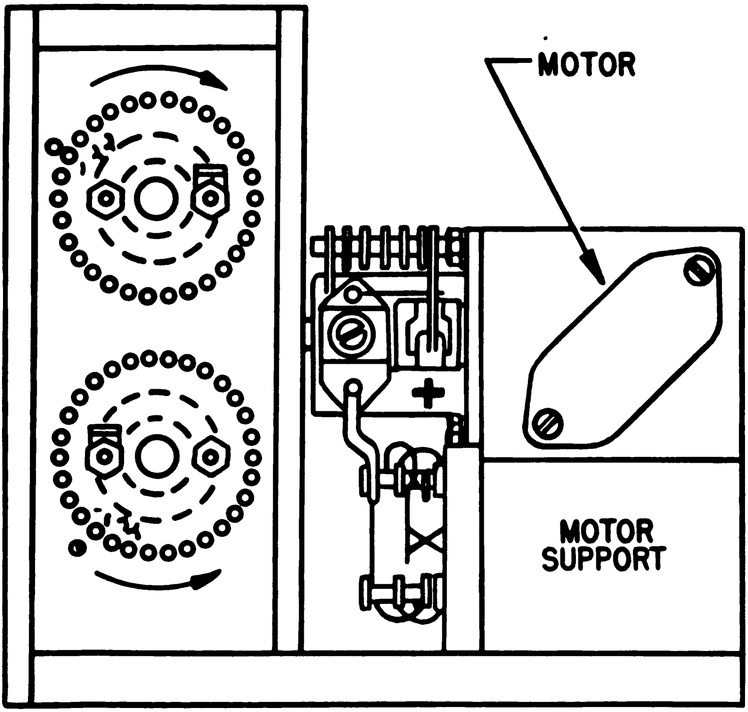


Figure 13–14.—Motor-driven commutating device.

Motor-driven commutators can be designed to provide typical sampling rates of 900 samples per second. With the average number of information channels used, this allows each channel to be sampled approximately 20 times per second.

ELECTRONIC COMMUTATION.—The multivibrator, the basic circuit used in electronic commutation, is discussed in chapter 7 of *Basic Electronics*. The use of the multivibrator as an electronic switch is also described in the same text in chapter 13, page 619. The trainee is referred to these chapters for information on the theory and operation of the circuits. Their application as commutating devices in pulse telemetering can be indicated by the example shown in figure 13–15, a block diagram of an airborne unit.

The MASTER KEYER is a free-running multivibrator used to generate the initial pulse of each sequence. This voltage is applied to the CHANNEL COLLECTOR and also as a triggering pulse to the multivibrator in channel 1. When triggered, the latter delivers one output pulse to the collector and a signal to the multivibrator in channel 2 which, in turn, applies a pulse to the collector and triggers the multivibrator

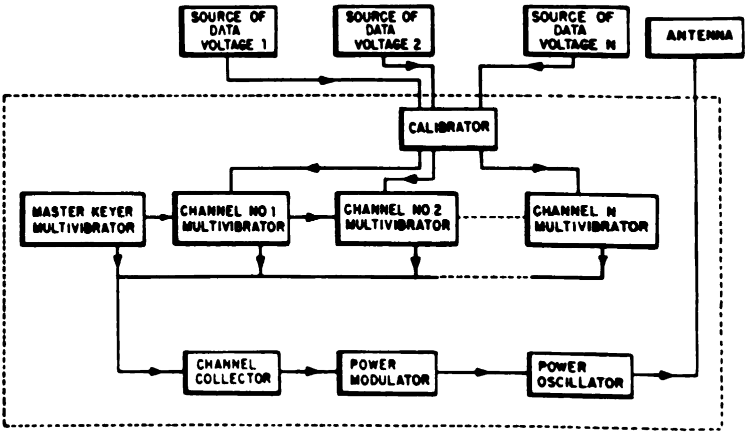


Figure 13–15.—Block diagram of airborne telemetering unit with electronic commutation.

of the next channel of the sequence. This process is repeated until all the channel multivibrators have operated.

Unlike the master keyer, the channel multivibrators are of the monostable type. The circuit produces no output until triggered by an input pulse; and when this occurs, it produces one pulse and then returns to an inactive state until triggered again. The width of the pulse produced depends upon the circuit constants and also upon the value of the applied voltage. In the case of the channel multivibrators, the width of the output pulse each applies to the collector is a function of the data voltage applied by the associated transducer.

After all the channel circuits have operated once to complete one sequence, the switching system remains quiescent until the master keyer again initiates another cycle of communication. The pulses in the output of the collector are applied to the modulator, which modulates the carrier generated by the power oscillator.

CHECKING, CALIBRATING, AND ADJUSTING TELEMETERING UNITS

The proper operation of telemetering equipment is a matter of the highest importance in missile evaluation. The equipments employed are usually fairly complex and require great care in calibration, adjustment, and repair. All these operations demand specific knowledge of the equipment involved as well as considerable skill and experience on the part of the technician carrying them out. No overall methods are valid for all systems since each is composed of specialized units designed for the particular purpose for which they are used. The Guided Missileman concerned with adjustment and maintenance of telemetering equipment must rely wholly upon information given in the publications pertaining to the particular units; and the detailed procedures for calibration, adjustment, and repair usually included in these must be followed exactly.

While no checks and tests can be described in detail, there are a few which are of sufficient general importance to be required in most instances. These include measurements of transducer outputs, checking and adjustment of oscillator frequencies, and checks of the output of pulse generating circuits.

Transducer outputs are checked against values given in the equipment handbook which indicate normal operation of the instrument in response to simulated missile conditions. The measurements of voltage must be done only with the type of instrument authorized in the handbook; and any adjustments must be made according to the directions given.

As indicated in table 13–1, subcarrier oscillators in F-M/F-M systems must operate at certain assigned center frequencies and must be deviated in frequency only within certain well-defined upper and lower limits. The center frequencies generated by each channel oscillator must be measured and adjusted to the assigned value; and the deviation of the subcarrier signals must be checked by applying standard input signals to the modulating circuits. The master oscillator of the telemetering transmitter must also be checked for proper frequency and tuned to the assigned value in the telemetering band.

Pulse generating circuits are checked for proper operation by the use of test signals developed in standard signal sources and by use of authorized testing and measuring equipment.

QUIZ

1. What factor makes telemetering a necessity in the guided missile field?
   a. A missile cannot be tested by a human pilot.
   b. Missiles generally fly at higher altitudes than aircraft.
   c. Telemetering supplements the guidance command signals.
   d. It would be dangerous to fly an aircraft in close proximity to a missile.
2. An early type of radio telemetering was used to
   a. measure the depth of ocean
   b. transmit weather data
   c. read the speed of the engine aboard ship
   d. measure fuel consumption of military engines
3. Missile telemetering systems operate by means of ______________ transmissions.
   a. light
   b. radar
   c. radio
   d. sound
4. The primary requirement of a missile telemetering system is the ability to __________ of data in a short period of time.
   a. gather, decode, and process a large amount
   b. gather, transmit, and process a small amount
   c. gather, decode, and process a small amount
   d. gather, transmit, and process a large amount
5. The F-M/F-M telemetering system employs a/an ________________ carrier.
   a. amplitude-modulated
   b. frequency-modulated
   c. pulse-modulated
   d. phase-modulated
6. In F-M/F-M systems, the number of missile functions telemetered may be as high as
   a. 14
   b. 18
   c. 30
   d. any required number
7. The device which frequency modulates each subcarrier oscillator is called a/an
   a. pickup
   b. end instrument
   c. telemeter pickup
   d. transducer

8. The carrier frequencies allocated for use in telemetering are in the band from
   a. 216 mc to 235 mc
   b. 216 kc to 235 kc
   c. 200 kc to 300 kc
   d. 200 mc to 300 mc

9. The transmitted carrier in telemetering systems is picked up at the receiving station and the subcarrier signals are separated by means of
   a. low pass filters
   b. band pass filters
   c. high pass filters
   d. discriminators

10. The permissible frequency deviation in the standard subcarriers is
    a. ±7.5%
    b. ±15%
    c. ±20%
    d. ±25%

11. The transducers convert the information to be measured into
    a. a-f signals
    b. p-f signals
    c. d-c voltages
    d. constant-frequency signals

12. An example of the variable reluctance transducer is the
    a. accelerometer
    b. linear potentiometer
    c. inductance pickoff
    d. capacitance pickoff

13. The saturable reactor is not used to measure voltages developed in high impedance sources because
    a. it will be unable to measure these voltages
    b. it is a power consuming device
    c. it is too large a unit to be used in close proximity
    d. there are no applications of this device

14. Which two oscillators are most commonly used as subcarrier oscillators?
    a. Hartley and Armstrong
    b. Phase shift and Colpitts
    c. Colpitts and Armstrong
    d. Hartley and phase shift

15. Missile telemetering transmitters differ principally from standard transmitters in
   a. physical form
   b. frequency
   c. operation
   d. basic circuity

16. The antenna system of a telemetering receiving station contains ________________ antennas.
   a. highly directional
   b. multi directional
   c. non directional
   d. low gain

17. The outputs of the signal channels are applied to
   a. recording devices
   b. dissipation net works
   c. servo systems
   d. antenna positioning devices

18. The general purpose of a magnetic recorder is for
   a. data recovery at a later time
   b. direct readings
   c. fidelity of reproduction
   d. ease of use

19. Commutating devices are used in pulse telemetering equipment as
   a. reducing devices
   b. switches
   c. power supplies
   d. multivibrators

20. For proper operation of missile telemetering equipment, which of the following is the requirement of principal importance?
   a. Checking, adjusting, and calibration
   b. Cleanliness of equipment
   c. Low power requirements
   d. High power requirements

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CHAPTER 14

MISSILE HANDLING AND TESTING

As a guided missileman you may be assigned to a billet concerned with one of several different types of missiles. Specific handling and testing procedures for these various missiles differ. However, the general principles and theory of these procedures will be discussed for all missiles in this chapter. Specialized missile test equipment has been developed for some missiles. Specific information and step-by-step procedures for these specialized equipments must be obtained from the technical manuals available on your station. Certain common types of electronic test equipment are used with the majority of missiles. These equipments will be covered in detail here.

Missile HANDLING is discussed in the first section of this chapter. The term handling, when applied to a missile system, refers to all the procedures and steps taken with missile components from original factory delivery through assembly and expenditure of the weapon.

An important phase of missile handling is TESTING. Prior to use, every missile must pass one or more system tests designed to check the guidance and control systems under conditions resembling those of actual flight. To facilitate this kind of testing, special test sets have been developed for each missile system. One of the major requirements of the Guided Missileman rating is proficiency in the use of these types of equipment, which are described briefly in the second section of this chapter.

As pointed out earlier, in addition to specialized test equipment, the missileman must understand and use many GENERAL-PURPOSE TEST INSTRUMENTS as well as various gages and measuring tools. Some of the more important examples of this class are discussed in the concluding section of this chapter. Other instruments, not discussed in detail, are covered by reference to appropriate chapters in the companion basic texts of this course, *Basic Electronics*, NavPers 10087 and *Basic Electricity*, NavPers 10086.

MISSILE HANDLING

Various specialized containers and handling equipments have been developed for each missile system. These equipments have been devised to assure the safety and to facilitate the handling of the missile components from the place of manufacture until their arrival at the firing installation.

The handling systems used are compromises between the following demands:

a. ABSOLUTE SECURITY OF THE MISSILE COMPONENTS. These components must be protected against damage from rough handling, humidity, vibration, static electricity, and tampering.

b. EASE OF HANDLING CONTAINERS. The containers must be of a size, shape, and weight that will allow safe and efficient handling in the depot assembly areas and on board ship.

c. CONFORMITY WITH SAFETY PROCEDURES. The procedures and containers must conform with applicable Naval Safety Precautions and Coast Guard Shipping, Storage and Safety Precautions regarding explosive and flammable material. When missiles are being transported overland, procedures and equipment should conform with Interstate Commerce Commission regulations regarding rail or truck transfer of explosive and flammable items.

The need for compromise becomes obvious when it is considered that the container design that allows the greatest

efficiency and rapidity in a ship-to-ship transfer on the high seas will not necessarily be the container that could provide absolute security to the contents. The requirements put on the container by these two functions can be in opposition.

Shipping Containers

The most important function of the container is to protect the missile components as much as possible from the damage that could occur during storage and handling. Should the missile component be susceptible to damage from dampness, air tight sealing must be provided and desiccant must be present in the container. Certain containers are pressurized with dry air. Pressurizing these shipping containers permits checking the joints and covers for escaping air, thereby insuring a sealed, moisture proof condition. The pressurized containers are filled with dry air, to a few pounds pressure, through an air filler valve located on the cover of each container. An air release valve on the same cover acts as a safety valve to prevent pressure build-up within the container which might be harmful to certain missile components. A desiccant (drying agent) is placed in a basket in the container to keep the moisture content at a minimum. A humidity indicator usually included in the cover, allows visual checking of interior humidity.

Rubberized hair cushions and sponge rubber paddings are used to prevent damage occurring as a result of vibration and shock. Firmly secured mountings hold the missile components snugly inside the container. The walls of the containers are sturdily constructed to protect the contents from damage by impact, droppage, or heavy joltings. Provision is also made for grounding the contents to the containers and for grounding the container themselves to eliminate any possible hazards from static electricity.

The exteriors of the containers are generally designed to allow the easiest possible handling for an object of their size, shape, weight and function. Skids and flat surfaces are present on both top and bottom sides of the cylindrical

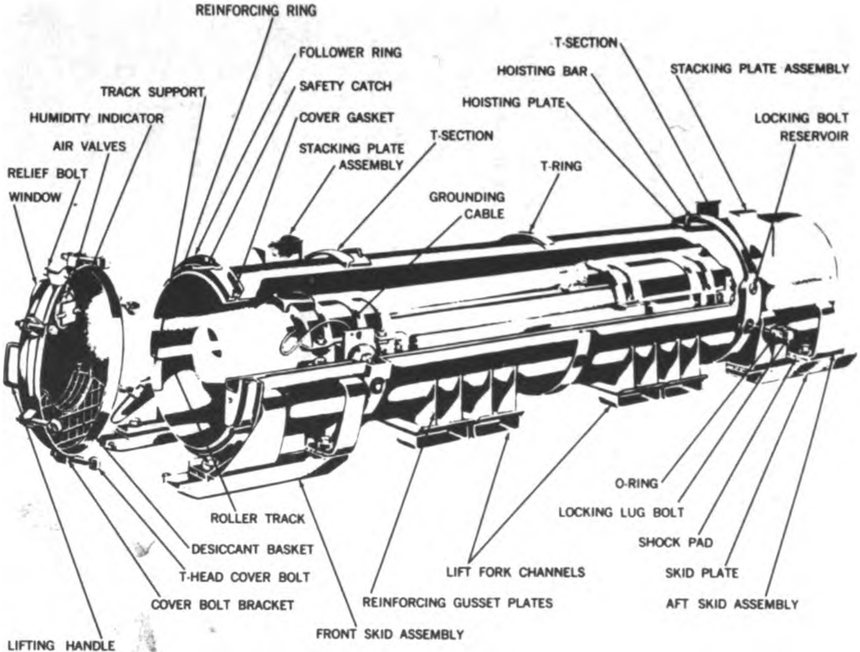


Figure 14—1.—Metal shipping container.

containers to allow stacking. The bottom surfaces are channeled to admit the prongs of a fork lift. The top surfaces of the larger containers are fitted to permit the insertion of eye-bolts for hooks and hoisting slings. These fittings are placed so as to maintain the balance of a properly loaded container when hoisted. The smaller size containers are fitted with hand grips to facilitate lifting and moving. Containers are fitted with quick-opening covers, though the degree of quickness depends on the size and sealing of the particular container.

Special handling equipment have been designed for the removal of contents from containers. Where heavy missile components are fitted into cylindrical containers, a roller and track arrangement is provided in the interior to ease the movement of the contents in and out of the container. Special stands have been devised to aid in the handling of the larger missile components. Overhead hoists, chainfalls, or tackle are installed in areas where the larger missile components are removed from or returned to the containers.

For replenishment at sea operations, some missiles are sealed in protective vapor barrier bags of composition, laminated material. The packaged missile components are then placed in special cradles as shown in figure 14–2 for the transfer. The cradles are returned to the replenishment ship for reuse.

Maintenance of Shipping Containers

Most shipping containers must be returned for reuse. They must be maintained in good condition. The containers are so designed that a simple inspection will show defects and a minimum amount of maintenance work will correct them. An inspection should be made each time a container is shipped to or through a depot assembly area, and maintenance should be performed as needed at that time.

If the container provides an air tight seal to protect the contents from humidity, the O-Rings or gaskets that maintain this seal must be checked very carefully. If there is any doubt about their serviceability, they should be replaced.

Figure 14–2.—Missile transfer at sea.

If the container has a mounting provided in it to hold the contents firmly in place, a careful check must be made of the fittings and locking devices to ensure that they work perfectly. No play should exist after the contents have been anchored in place. Where felt covered or rubber coated supports are used within the container, these must be checked visually to ensure that they are in good condition and will protect the missile component surfaces from burrs, scratches, or similar damage.

The condition of all THREADED surfaces in the containers should be checked visually. Because power drivers are often used in tightening down the lock-nuts, sealing bolts, and securing bolts, there is always a chance of stripped threads. Any stud, nut, or bolt showing evidence of cross-threading or strippage should be replaced immediately. The metal in a nut, bolt, or stud will stretch slightly after tightening down. If excessive force is used in tightening, an appreciable stretch will occur that will eventually make a tight seal impossible. If any play exists between a nut and bolt when correctly threaded, they should be replaced.

A visual inspection of the container body should be made to ensure that no dents, tears, punctures, or other damage is present. The painted surfaces should be in good condition. Any stenciled information on the outer surfaces of the containers should be clearly legible. Information that is no longer pertinent to the container or to its contents may be painted over.

When any defect is noted in inspection, or at any other time, a tag describing the nature of the damage and giving whatever information that may be known about the cause of the damage should be attached to the container. Defective containers should be sent as soon as possible to the repair shops of the appropriate depot assembly area.

Missile Logistics

The processes by which missile sections and components move from the manufacturer to the ultimate firing activity are indicated by means of a flow diagram in figure 14–3.

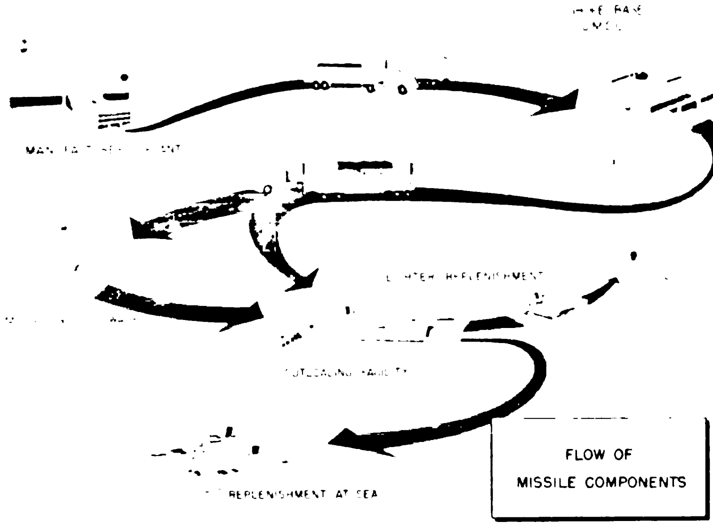


Figure 14–3.—Missile supply flow diagram.

Missile sections and boosters are shipped from their respective manufacturing sources to depots, which include missile assembly and service installations. At the depots the missile sections are unpacked, assembled, inspected, and repackaged for further shipment to firing activities. The extent of missile reassembly at the depots depends on intended use by the firing activities. In general, missiles will leave the depot in a more nearly assembled condition than that in which they arrived. At the firing activity missile sections which have not yet been assembled will be mated and then stowed in a missile magazine. The firing activity will perform periodic tests and inspections of their missiles.

SPECIAL TEST SETS

Special test sets have been developed to test specific missiles. These sets are often referred to as GO-NO-GO testers. The test set is designed to give an overall indication of whether or not the missile is ready for firing. The set pro-

grams a simulated missile flight and checks missile performance against known standards. The results of the test are indicated by means of indicator lights.

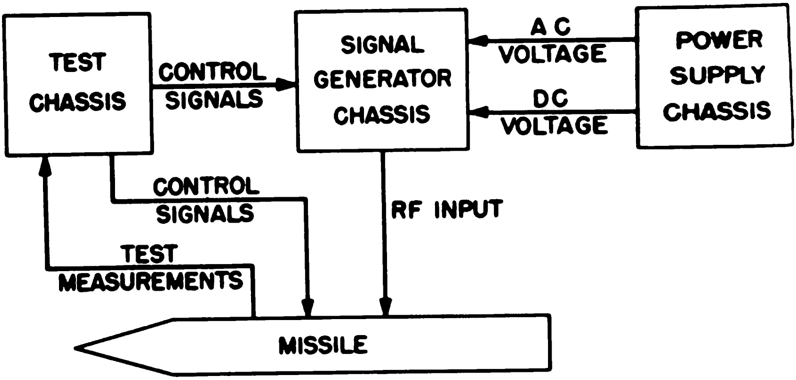


Figure 14–4.—Missile test set functional diagram.

A typical tester for a beam rider missile can be divided into the following three sections:

1. Test Chassis
2. Signal Generation Chassis
3. Power Supply Chassis

A block diagram of these three sections and a missile under test are shown in figure 14–4.

The Test Chassis

The Test Chassis controls itself, the Signal Generator Chassis, and the missile during the testing operation. It (1) provides certain control signals to the missile to simulate flight conditions, (2) performs the test measurements, (3) indicates test results, and (4) contains auxiliary testing and trouble shooting devices.

Automatic simulation of missile flight is accomplished by means of a programmed tape which activates CONTROL RELAYS and TEST RELAYS. A cam shaft is sometimes used instead of the programmed tape.

The CONTROL RELAYS actuate each simulated event in the missile flight. Certain control relays change operating conditions of the missile, such as application or removal of electrical, air, and hydraulic power. The position of these relays can also be selected by manual switches if automatic tape operation is not desired. Other control relays are connected to the Signal Generation Chassis to select the desired signal output.

The TEST RELAYS supply (1) reference voltages and (2) samples of each voltage under test to a comparator. The two voltages are fed alternately to an amplifier. The output of the amplifier, a square wave, fires a thyratron if the difference between the two voltages exceeds the permissible maximum. The thyratron controls a relay to indicate a good or bad individual test. Signals from this relay are sent through the test relays to group relay indicator lights. At the end of the tape program, a group indicator red light will be illuminated if any test monitored by a particular group has failed. A GOOD TEST, green indicator light will be illuminated if all missile tests have been passed.

A general purpose vacuum tube voltmeter is mounted in the test chassis. Various missile or test set voltages can be measured by this voltmeter by means of a manual selector switch. The meter can thus be used for troubleshooting either the missile or the test set itself.

The Signal Generator Chassis

The Signal Generator Chassis provides a simulated guidance beam for the missile. In actual flight the missile steering system detects the phase difference between the amplitude modulation and frequency modulation of the guidance beam plus the amount of amplitude modulation and transforms this information into control surface movements that bring the missile back to the beam nutation axis. This process was explained in detail in chapter 8 with the exception that the explanation in chapter 8 was of a system which used coded pulses instead of frequency modulation. The basic principles involved are identical. In order to simulate this

beam a signal must be generated with frequency modulated pulses. Means must also be provided to modulate the amplitudes of the pulses for certain phases of testing in order to simulate displacement of the missile from the axis of beam nutation.

The signal generator uses a synchronous motor to rotate two iron wheels. Each of these wheels has radial grooves etched on one face. The first wheel is called the FM PULSE WHEEL, and the second wheel is called the AM WHEEL.

The FM PULSE WHEEL, as its name implies, is used to produce the desired frequency modulated pulses. A pickup assembly, consisting of a permanent magnet and coil, is mounted adjacent to the etched portion of the wheel so that the flux path of the magnet is interrupted by the etched grooves. As the wheel rotates a series of pulses are induced in the pickup coil. The wheel rotates at a speed which will produce the desired basic pulse frequency. The radial spacing of the grooves in the pulse wheel is varied so as to introduce the desired percentage of frequency modulation. These pulses are fed to a pulse shaping and amplification circuit. The pulses are then fed through a modulator to modulate the pulses of a klystron. The klystron output is the desired signal with frequency modulated pulses.

The AM WHEEL is used to modulate the amplitude of the klystron output. This wheel extends into a slotted section of waveguide. As the wheel rotates, the signal in the waveguide is amplitude modulated by the varying degree of attenuation to which it is subjected. Provision is made to bypass the AM circuit when desired.

Since the FM and AM wheels rotate with a fixed phase relationship, several pickoff assemblies are used with each FM wheel and are accurately positioned for the desired AM–FM phase relationships. Simulated missile position for the test is determined by selecting the appropriate pickoff assembly. A range attenuation device can be added to simulate increasing range by weakening the signal received by the missile.

The Power Supply Chassis

The Power Supply Chassis provides the various d-c voltages required for the operation of the tester. Conventional and electronic rectifiers are used. The power supply also provides the various a-c voltages needed. The frequencies of the a-c voltages are critical to the operation of the tester. Tuning forks and count down circuits supply these accurate frequencies.

It should be remembered that the test set described above is an imaginary set. However, the operation of this set is typical of the actual sets that you will encounter. Detailed instructions for the operation of these sets are contained in the technical manuals accompanying the equipment.

GENERAL-PURPOSE TEST EQUIPMENT

In addition to specialized missile test devices, numerous types of general-purpose instruments are employed by the Guided Missileman in checking, maintaining, and repairing missile components and related test equipment. These consist mainly of electronic and electrical test sets and meters; but many hand tools such as calipers, micrometers, and various kinds of gages are included in the missileman's list of standard equipment.

This section is concerned principally with the instruments used in electrical and electronic testing. It is intended for study in conjunction with three basic texts: *Basic Electricity*, NavPers 10086; *Basic Electronics*, NavPers 10087; and *Basic Hand Tool Skills*, NavPers 10085. The chapters of these books which supply the required information are referenced throughout the following pages.

The source of major importance is chapter 13, *Basic Electronics*, which discusses the principles and construction of many test devices used in the work of the Guided Missileman, such as synchroscopes, electronic switches, impedance bridges, tube testers, and signals generators.

The basic electrical indicating instruments are the voltmeter, the ohmmeter, and the ammeter. The first of these, the voltmeter, is a standard device in most missile measurements, being employed in troubleshooting, in calibration of test equipment, and in the setup procedures of many kinds of specialized missile test sets.

THE USE OF THE VOLTMETER.—*Basic Electricity*, chapter 9, contains the necessary information on the operating principles and construction of the d-c voltmeter and of the standard a-c meters, the electrodynamometer, and the iron-vane. Of these, the d-c voltmeter is the instrument most frequently used for localizing defects in missile components and in maintaining test equipment.

Voltage measurements are made at various points in the stage or stages suspected of being at fault. The observed voltage values are then compared with the normal values given in the appropriate *Handbook of Service Instructions*, and from the comparison the defect can usually be isolated.

Voltage checks are most effective when applied within a single stage after previous checks have been made to localize the fault as closely as possible. This is particularly true with complex missile electronic circuits, since any attempt to measure all the voltages present in most of these would be a very time-consuming process.

It is important that the voltmeter used in checking defective components conforms to the specifications listed in the equipment handbook. The meter should have the same SENSITIVITY as that used by the manufacturer in making the original voltage measurements; otherwise the values observed may not match the standard values. As explained in the basic text, meter sensitivity is rated in ohms per volt, or the total resistance of the meter and dropping resistor divided by the voltage required for full-scale deflection. The higher the sensitivity, the lower the current drain through the meter, and the greater is the accuracy of the measurement.

When setting up or calibrating missile test equipment, various a-c and d-c voltages must be adjusted to specified standard values. In these procedures electronic voltmeters (also called vacuum-tube voltmeters) are usually required. Compared with a standard voltmeter, an instrument of this type has the advantage of greater input impedance. Hence, it introduces less error due to changes made in circuit operation when the meter is applied. The theory of operation of a representative meter of this class is given in *Basic Electronics*, chapter 13.

RESISTANCE CHECKS.—The ohmmeter is the basic instrument used to determine the resistance of a circuit or a circuit element. The theory and construction of the series-type and the shunt-type ohmmeters are discussed in *Basic Electricity*, chapter 9, which also describes a more specialized type of instrument, the megohmmeter, or megger.

The use of resistance checks for locating defective parts in electronic circuits is somewhat similar to the process of voltage checking, except that the equipment must be switched off and the suspected parts measured with an ohmmeter. The observed resistance values are then compared with the normal values given in the equipment handbook in order to identify the malfunctioning part. This method, like voltage checking, is most effective after the trouble has been isolated to a single stage.

Tests made to determine continuity or shorts in electric cables are typical examples of routine uses of the ohmmeter. The megger is also employed for testing cables. It contains a source of fairly high voltage (usually a hand-powered generator) which is applied to the cable in order to test it under conditions approximating those of operation. It is used principally for detecting high-resistance shorts and for measuring leakage in insulation.

CURRENT MEASUREMENTS.—The principal classes of current-measuring devices, both d-c and a-c, are described in chapter 9, *Basic Electricity*.

The ammeters used in missile systems test equipment and component test sets are usually panel-mounted instruments.

In these applications they indicate the current drain of the major electrical circuits and thus provide a valuable first step in finding trouble. When ammeters are not included as parts of the equipment, current measurements can be made only after the circuit wiring has been opened and the meter inserted in series with the part in question. This is often a time-consuming procedure; hence, voltage or resistance checks are usually preferable.

The Cathode-Ray Oscilloscope

The cathode-ray oscilloscope is one of the most useful and versatile of test instruments. It is essentially a device for displaying graphs of rapidly changing voltage or current, but it is also capable of giving information concerning frequency values, phase differences, and voltage amplitudes.

The oscilloscope is used to trace test signals through missile receivers and video amplifiers, to measure percentages of modulation in missile test equipment signal simulators, and to localize the sources of distortion in test equipment and in missile components. It is used to measure peak a-c and r-f voltages, to measure video-amplifier gain, to make overall frequency response curves, and to study dynamic tube characteristic curves.

These are but a few of its many applications. The discussion here is confined to some of its uses in measurement and maintenance of electronic equipment. For a coverage of the theory of the cathode-ray tube and of the basic circuits and controls of the instrument, the reader is referred to *Basic Electronics*, NavPers 10087, chapter 13.

THE AN/USM-24 OSCILLOSCOPE.—Missiles employing radar guidance respond to pulses which have distinctive waveforms, spacing, and timing. When observing these signals while testing the missile units and adjusting the associated test equipment, it is necessary to have an oscilloscope with features which make it suitable for pulse displays. A typical instrument of this type is the AN/USM-24, which is shown in figure 14-5. It is capable of presenting square-

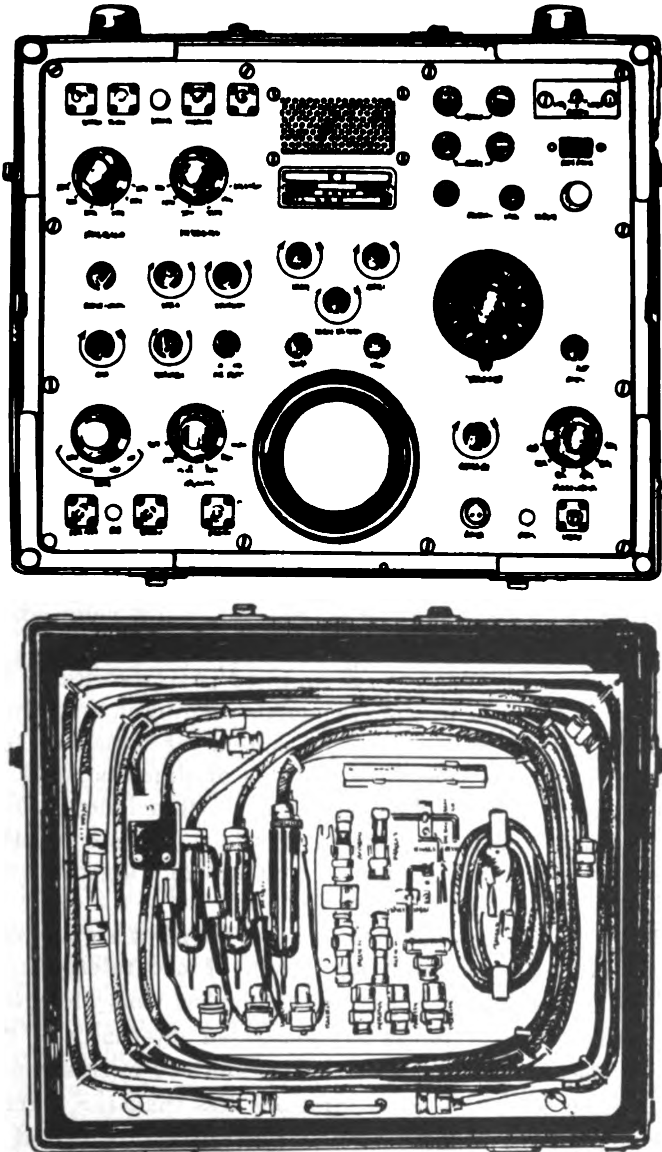


Figure 14–5.—The AN/USM–24 Oscilloscope.

wave signals with small amounts of distortion and has self-contained means for measuring pulse duration, spacing, and amplitude.

Since it is usually desirable to observe the amplitudes of signals with respect to time, the AN/USM–24 provides horizontal sweep voltages which vary linearly and serve as the time base. The horizontal deflection system can be operated either in periodic fashion, or it may be set to give synchroscope operation in which a sweep of short duration is generated only when a synchronizing signal is present.

By means of a SWEEP switch and a FINE-SWEEP potentiometer, the time base may be varied within the limits of 1.25 and 125,000 microseconds. Also, any portion of the time base over 10 microseconds in duration can be selected and expanded for more detailed observation of the signal.

The signal amplifiers respond uniformly over a wide frequency band so that flat-topped pulses are displayed with minimum distortion. The signals are presented as vertical deflections; and the sensitivity of the vertical amplifiers is such that those with amplitudes from 0.01 to 150 volts can be observed directly.

Two types of test probes are supplied as accessories. One enables the operator to observe signals ranging in amplitude from 150 to 600 volts. The other is used for signals up to 2 volts in amplitude when low amounts of shunt-capacitance loading are required. The vertical channel includes a delay line (with 0.055-microsecond delay) which makes it possible to observe the leading edges of pulses triggering the horizontal sweep circuits.

The time durations of signals or portions of signals displayed may be measured by means of accurately timed marker pulses, which appear as intensified dots along the trace. The marker pulses are generated internally at five fixed repetition rates: 0.2, 1, 10, 100, and 500 microseconds. For measurements of time durations less than the marker intervals, the horizontal length of the trace can be varied by means of the horizontal-gain control. This permits inter-

polation between the markers by use of the grid on the screen.

For observation of high-speed transient voltages the linear time base produces a gate which intensifies the electron beam during the "go" time only, thus producing traces with high intensity without injury to the screen of the cathode-ray tube.

All operating controls and connectors are either placed on the front panel or else are accessible through the ventilating door on the rear of the case. All accessories are mounted on a tray on the oscilloscope cover. The controls and connectors are arranged functionally and are labeled so that the instrument can be operated without reference to the instruction manual.

Precision Frequency Measurements

The discussion of frequency measuring equipment in the following pages should be studied in connection with the section entitled "Frequency Standards" in chapter 13, *Basic Electronics*, NavPers 10087.

Heterodyne frequency standards and also wavemeters are used in the work of the Guided Missileman. His duties require, in addition, that he use instruments of more elaborate design which are capable of measuring numbers of random pulses as well as the frequencies of periodic waves.

Frequency Meter AN/USM–26

The AN/USM–26 is a precision laboratory instrument designed for measurements of frequency, time intervals, periods, frequency ratios, and "total events." The capabilities of the instrument are such that it may be used as a secondary frequency standard when calibrated regularly by a fairly simple method.

The complete equipment consists of the FR–38A/U Frequency Meter and two plug-in units, only one of which is used at any one time. The appearance of the control panel of the FR–38A/U is shown in figure 14–6. This unit con-

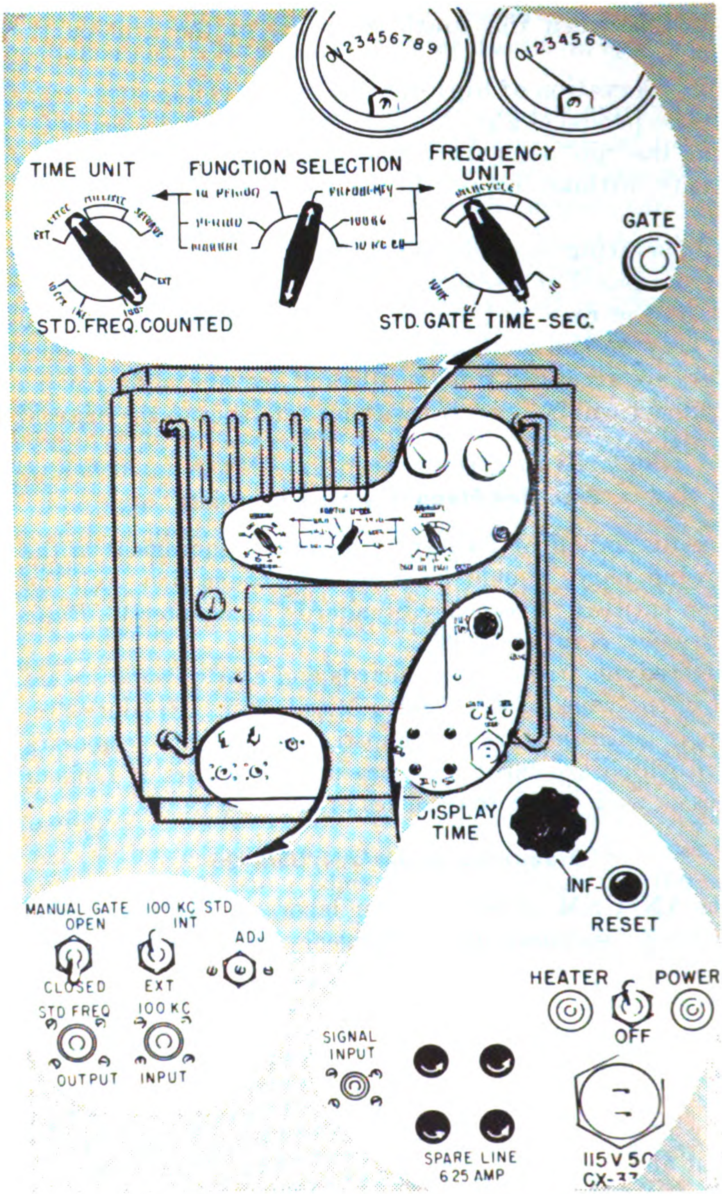


Figure 14–6.—Front-panel controls of FR–38A/U Frequency Meter.

tains the counting and gating circuits upon which the operation of the instrument largely depends. The plug-in units are designed to perform separate functions, but either may be used to measure unknown frequencies up to 10 megacycles per second.

One of the plug-in units, the MX–1636/U, the Time Interval Unit, contains attenuator and trigger circuits used in measurements of time intervals. The other, the MX–1637/U, is the Frequency Converter Unit, which mixes the proper harmonic frequency of a standard signal with the unknown frequency to be measured. The converter equipment is employed for frequency measurements above 10.1 mc.

BASIC OPERATION.—Unlike more familiar frequency meters, the FR–38A/U counts, cycle by cycle, the variations in the signals fed into it from the plug-in unit in use. The frequency meter contains no tuned circuits in the path of signal flow; hence, the incoming signals need not be periodic, but may have the random character of the output of the Geiger counter.

In measuring frequency, counting circuits in the principal unit count the number of pulses occurring during an interval of time determined by an internal oscillator. An indication of the average number of "events" or signal variations taking place during the interval is made by means of two meters and several etched numeral plates mounted on the panel. The counting operation is repeated automatically, each cycle of counting lasting for the interval of time determined by the time-base oscillator.

A simplified block diagram showing the principal units required in the FREQUENCY function of the instrument is given in figure 14–7. The equipment consists principally of of a digital counter, into which is fed the signals to be measured through a signal gate. The gate is opened by the time-base generator to permit application of the signal to the counters. After a very accurately determined interval of time, the gate is closed until the start of another cycle of counting.

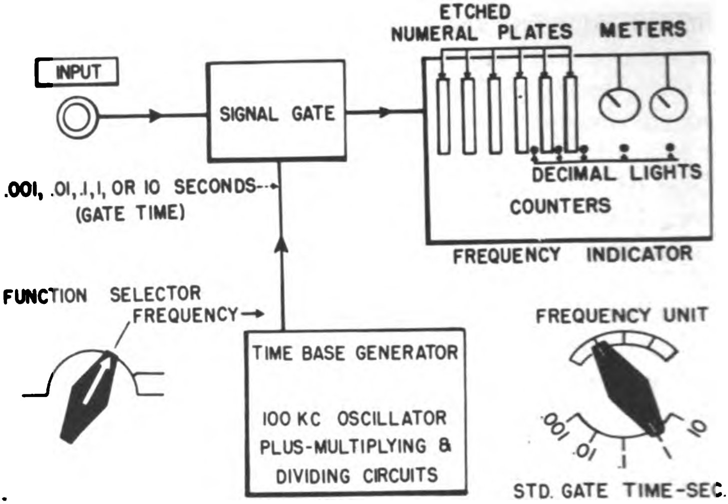


Figure 14–7.—Simplified block diagram: AN/USM–26, frequency function.

The gate times, or counting intervals, are integral powers of 10 times 1 second, ranging in value from 0.001 to 10 seconds. An illuminated decimal point on the front panel shifts according to the gate time selected so that the meter always reads directly in kilocycles.

In addition to the frequency function, the FR–38A/U has provisions for measuring the period of the applied signal (reciprocal of frequency) and for determining accurately the time interval between two signal events. A summary of the capabilities of the complete set is given in table 14–1.

As may be seen in the table, the accuracy of the frequency meter is dependent upon the accuracy of calibration of the internal standard oscillator and also upon an error of 1 count, which is inherent in the signal-gate circuit used. The oscillator operates at 100 kilocycles with a normal drift of no more than 2 parts per million per week. However, the percentage of error with signals below 10 kilocycles increases rapidly because of the error in the signal-gate circuit.

TABLE 14–1.—SPECIFICATIONS FOR FREQUENCY METER AN/USM–26.

FREQUENCY MEASUREMENT

Range:	10 c. p. s. to 100 mc. (direct reading).
Accuracy:	±1 count ±0.0002 percent* (±0.1 c. p. s. ±0.0002 percent on 10-second gate).
Gate Time:	0.001, 0.01, 0.1, 1, or 10 seconds; selected by panel control.
Display Time:	Continuously variable from 0.3 to 5 seconds by a panel control. In manual operation, display time continues until reset.

PERIOD MEASUREMENT

Range:	0.01 c. p. s. to 10 kc. (100 microseconds).
Accuracy:	±0.03 percent.
Gate Time:	Counts for 1 or 10 cycles of input signal as desired.
Units of Measurement:	0.1 microsecond, 0.01 millisecond, 1 millisecond, or 0.1 second.
Display Time:	Same as for frequency measurement.

TIME INTERVAL MEASUREMENT

Range:	1.0 microsecond to 10,000,000 seconds.
Accuracy:	±0.1 microsecond ±0.0002 percent.*
Independent Start and Stop Channels:	Triggers from either positive- or negative-going input voltages at levels from −200 to +200 volts. Separate or common direct-coupled inputs.
Display Time:	Same as for frequency measurement.

*Internal standard.

The accuracy figure of 0.0002 percent is due to the internal crystal oscillator, which has a long time stability of within two parts/million/week. Short time stability is within one part/million. A panel connector permits use of an external 100 kc. primary standard signal to obtain higher accuracy.

When measuring signals below 316 kilocycles, greater accuracy is obtained by determining the period of the wave that can be obtained by direct frequency measurement. The meter has provisions for measuring the period, or the average value of 10 periods of signals ranging in frequency down to 0.01 cycle per second. Below this frequency the time interval unit can be used to measure periods as long as 10 million seconds (approximately 1,175 days).

Wavemeters

Wavemeters consist essentially of tuning circuits calibrated for measuring frequency. Although the accuracy of the typical wavemeter is not as high as that of heterodyne frequency meters, these instruments have the advantage of comparative simplicity and most can be carried about easily.

Many types of tuning circuits are used in wavemeter applications; the exact kind of circuit employed depends largely upon the frequency range of the instrument. Resonant circuits consisting of coils and capacitors are used in low-frequency wavemeters. Butterfly circuits, adjustable sections of transmission line, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters: the absorption, the reaction, and the transmission types. An absorption meter is composed of a tuning circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type is loosely coupled to the circuit to be measured; and the tuning circuit of the wavemeter is then adjusted until the current indicator shows maximum deflection. The frequency of the circuit under test is then read on the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit measured. For example, the wavemeter is loosely coupled to the grid circuit of a low-frequency oscillator. The meter is adjusted for resonance with the oscillator frequency. The setting of the wavemeter dial can be made by observing the

grid-current meter of the oscillator. At resonance the wavemeter takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radio-frequency energy and an indicator, energy is transferred to the indicator only when the wavemeter is tuned to the source frequency to be measured. The value of this frequency is then determined by calibration data suitable for the particular wavemeter.

Transmission wavemeters are widely used for measuring microwave frequencies. The example illustrated in figure 14–8 contains a tunable cavity which serves as the necessary frequency-selective element. The resonant frequency of the cavity can be varied by means of a plunger that is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity effectively reduces the cavity size and increases the value of the resonant frequency; withdrawing the plunger causes the cavity to resonate at a lower frequency.

Microwave energy from the equipment under test is fed into the wavemeter through one of the inputs (A) or (D) shown in figure 14–8. The signal is rectified by a crystal circuit and the amplitude of the resulting current is indicated on the current meter, M.

The instrument can be used either as a transmission or as an absorption meter. In the former case the signal to be measured is coupled into the circuit by input (A) and out through loop (C) to the crystal rectifier. The cavity adjusting plunger is set for a maximum reading of the current meter. The micrometer reading at this setting is then used with a calibration chart supplied with the meter to determine the unknown frequency value.

When the source signal to be measured is relatively weak, such as that of a klystron oscillator, the wavemeter is usually employed as an absorption instrument. Connection

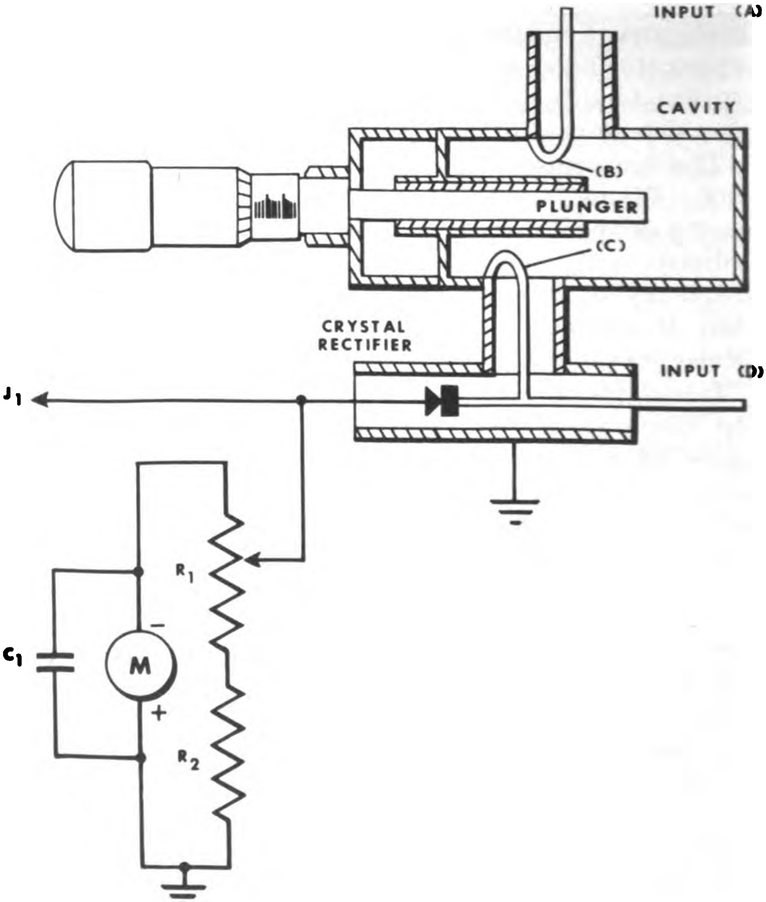


Figure 14–8.—Typical cavity wavemeter.

to the wavemeter is made at input (D); and the r-f loop (C) then functions as an injection loop to the cavity. When the cavity is tuned to resonance with the source signal, the current indicated on the meter dips. Off-resonance settings of the cavity result in high values of rectified current; hence, the plunger adjustment is varied until the meter reads a minimum value. The frequency can then be determined from the micrometer reading and the calibration chart.

The potentiometer, R_1, (fig. 14–8) is used to adjust the meter sensitivity. The video jack, J_1, is provided for observing video waveforms when the instrument is employed in conjunction with a test oscilloscope.

Spectrum Analyzers

When a radio-frequency carrier wave is modulated by keying, by speech waveforms, or by pulses, the resulting wave contains many frequencies. The original carrier frequency is present, together with two groups of new frequency components called SIDEBANDS. One group of sidebands is displaced in frequency below the carrier. The other group consists of sidebands greater in frequency than the carrier. The distribution of these frequencies, when shown on a graph of voltage or power versus frequency, is called the SPECTRUM of the wave.

Spectrum analyzers are electronic test instruments used to provide visual indications of the frequency components present in modulated waves and in other complex signals.

For introductory material on these instruments, the trainee is referred to chapter 13, *Basic Electronics*, NavPers 10087. The basic text discusses the fundamental operating principles, gives a block diagram, and describes a representative example of this type of instrument.

Spectrum analyzers are employed extensively for checking the outputs of transmitting tubes such as magnetrons, which are used in pulse radar systems. In this kind of analysis unwanted effects such as frequency modulation of the carrier wave can be easily detected. In pure amplitude modulation by square pulses, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation.

A spectrum representing correct operation is shown in (A) of figure 14–9. Examples of undesirable magnetron spectra are shown in (B) and (C). The latter indicate trouble in the modulator, the tuning system, or in the magnetron tube.

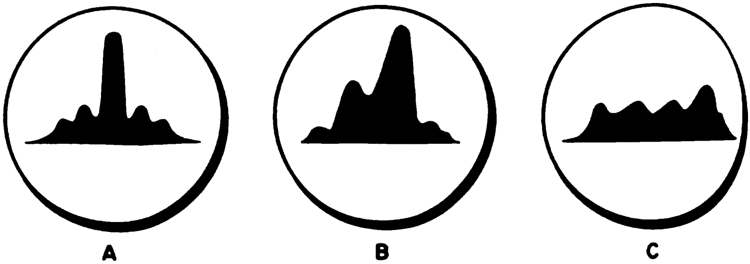


Figure 14–9.—Frequency spectra.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 14–9. In some spectrum analyzers this fact serves as the basis for measuring the frequency of the carrier wave. A highly selective tuning circuit is provided in the receiver section of the instrument to function as a trap, which prevents a very narrow band of frequencies from appearing in the display. As a result of its use, a narrow gap appears in the spectrum corresponding to the frequency to which it is tuned. The tuning adjustments of the trap are calibrated; and when the gap is made to appear in the center of the spectrum, the carrier frequency can be determined from the tuning dial of the trap.

Testing Crystal Rectifiers

The function of a crystal rectifier test set is to provide a quick and accurate means of testing a crystal rectifier in the field. Although the complete testing of a crystal rectifier is an elaborate procedure requiring precision radiofrequency test equipment, the test sets usually provided are sufficient for determining whether or not the crystal is satisfactory for use. Crystal testing is accomplished by measurement of the forward and backward resistance, and usually the back current at 1.0 volt.

A crystal rectifier is a device used for converting r-f energy into unidirectional current. It usually consists of a small piece of silicon in contact with a thin tungsten wire (called a cat whisker), both of which are mounted in a

small cartridge-type container. The rectification takes place at the contact between the silicon crystal and cat whisker, and is due to the fact that the resistance in one direction is greater than that in the other direction as in a vacuum tube used as a rectifier or detector. The properties of the rectifier depend critically on the type of contact area, and the place of contact. The crystal rectifier has been carefully adjusted at the factory; it should not be upset by tampering with the setscrew.

A crystal rectifier is illustrated in figure 14–10. The crystal is designed so that current normally flows from the

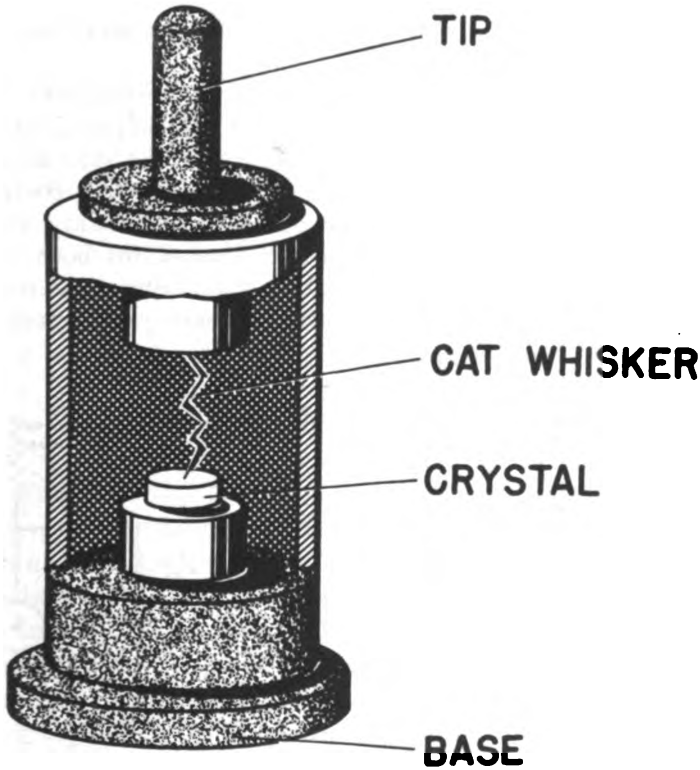


Figure 14–10.—Crystal rectifier.

tip to the base (tungsten to silicon). The area of contact within the crystal rectifier housing is very small, and if too much current is passed through the cartridge, the resulting heat will damage it, causing the operation of the crystal rectifier to be impaired or the unit to burn out completely.

Crystal rectifiers may be damaged by static discharges. The operator should be sure that any static charge which may be present on the body is discharged by momentarily touching (grounding) a finger on the hand to the ground contact of the test set or equipment in which the crystal is to be installed.

Because of the possibility of damage due to strong r-f fields which may be present, crystals are stowed in metal containers or in metal foil except when they are being tested or used.

The circuit diagrams of a typical crystal rectifier test set are illustrated in figures 14–11 and 14–12. The figures show two arrangements of the same device. The test set can be changed from the resistance measuring arrangement to the back-current circuit by the action of a selector switch. The meter shown in the two figures is calibrated for both resistance and current measurements. It contains a 0–1 milliampere movement with an internal resistance of approximately 100 ohms.

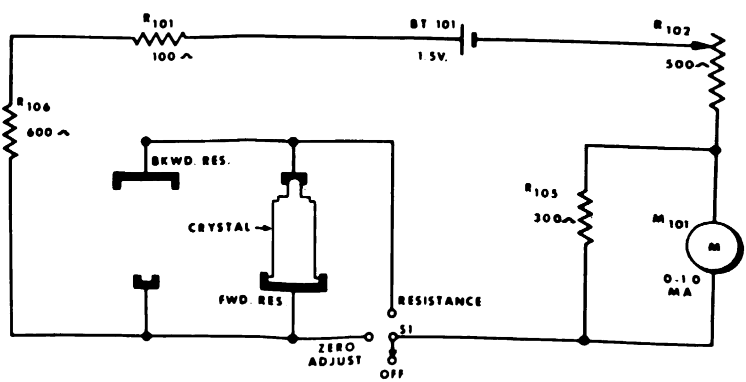


Figure 14–11.—Rectifier test set schematic—resistance measurement.

The circuit shown in figure 14–11 is used for forward and backward resistance measurement and is similar to the circuit of a simple ohmmeter. With switch $S1$ set to the ZERO ADJUST position, the milliammeter is first set for maximum (1.0 ma.) current, or zero indicated resistance, by adjustment of the series potentiometer R_{102}. The forward or backward resistance can then be measured by rotating $S1$ to the appropriate position and placing the crystal rectifier in the proper holder.

If no further change has been made in the position of the control R_{102}, the additional resistance which the crystal rectifier introduces into the circuit causes a decrease in the current flow, and the meter will then deflect to some point on the scale other than the full deflection.

The forward, or "front," resistance of the crystal is the resistance measured with normal current flowing (comparable to the cathode-to-plate current flow in a diode vacuum tube). The crystal rectifier is considered unfit for use if this resistance is greater than 500 ohms.

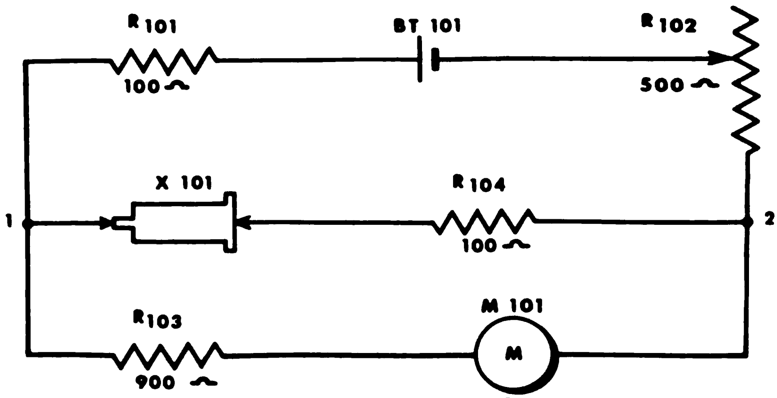
The backward, or "back," resistance of the crystal is a measure of resistance to current flow from the crystal to the whisker of the rectifier. This current flows from the rectifier base to the tip and is comparable to any current flowing from the plate to the cathode in a diode vacuum tube. The crystal rectifier should be rejected for use if the ratio of back resistance to front resistance is less than 10 to 1.

For example, if the meter reading is 400 ohms when the forward resistance is measured, then the back resistance must be at least 4,000 ohms or more, if the crystal is considered to be usable.

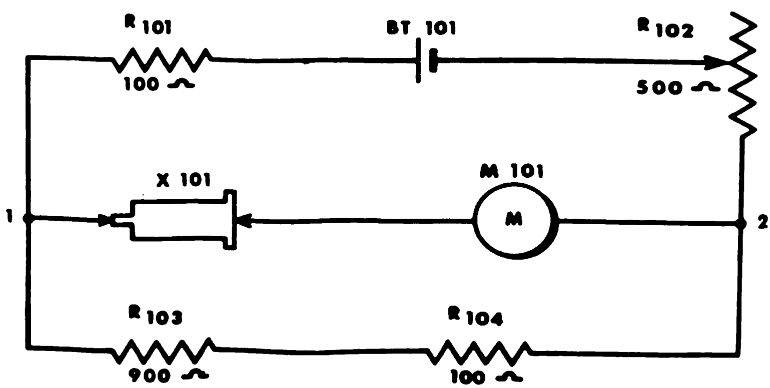
In addition to the circuit arrangement for checking the resistance ratio of the crystal rectifier, many test sets are provided with means for measuring the back current through the rectifier with an applied voltage of 1.0 volt. This is a more accurate measure of the condition of the crystal than the resistance-ratio check. The circuit arrangements for

this check are illustrated in figure 14–12. In (A) of the figure the circuit is shown in the condition used for the initial voltage adjustment.

Before the back current is measured, the meter must be adjusted so that an effective voltage of 1.0 volt is impressed across points 1 and 2. Since the back resistance of a crystal



(A) BACK CURRENT ZERO ADJUSTMENT



(B) BACK CURRENT

Figure 14–12.—Rectifier test set schematic—back current measurement.

rectifier is a high value, the effective resistance of the parallel circuit between points 1 and 2 (A) of the figure is essentially that of the meter and R_{102}, or 1,000 ohms. The full-scale reading of the milliammeter is 1.0 milliammeter; therefore, an adjustment of R_{102} resulting in full-scale deflection of the meter insures a voltage of 1.0 volt across the parallel circuit.

After the voltage has been adjusted, the circuit is switched to the condition shown in (B) of figure 14–12 to measure the back current. In this condition the position of the crystal rectifier and R_{103} are exchanged so that the crystal is now in series with the milliammeter which has negligible resistance compared with that of the rectifier. With 1.0 volt impressed across this circuit, the meter then indicates the current flowing through the crystal rectifier. The magnitude of this current is inversely proportional to the backward resistance of the crystal. The scale of the meter is usually marked to indicate the maximum limits of back current for the crystal rectifiers in common use.

The maximum allowable back current varies somewhat with temperature. The lower the temperature, the lower the maximum limit of back current. Temperature correction tables are included with the instruction manuals of most test sets. These should be consulted when the surrounding temperature is considerably lower or higher than 70° F. (approximately 22° C.).

R–F Power Measurements

In the initial setup procedures of certain missile test equipment (both systems tests and components test sets) it is necessary to measure and adjust the power of microwave signals. For example, with radar-signal simulating equipment, the test signal supplied in one phase of checkout is required to be of a specified power value in order to serve as a reference.

The missile response is checked first with inputs set to the reference value, which represents the radar energy received at a particular range. Signal power is then pro-

gressively reduced by inserting known values of attenuation in the source, thereby simulating signals received at greater ranges. It is important that the reference power be set accurately; to accomplish this, it is usually measured by means of an instrument containing a heat-sensitive element called a BOLOMETER.

POWER MEASUREMENT WITH BOLOMETERS.—The bolometer method of r-f power measurement is based on the detection of changes in resistance caused by changes in temperature. The bolometer element is mounted so that it is heated by absorption of r-f energy. The resulting change in resistance serves as a measure of the signal power, which is determined by means of an auxiliary bridge circuit in which the bolometer forms one of the arms.

The principal components in bolometer measurements are the mount; the bridge; and the bolometer element, which may be any of several types. The bolometer element is placed in the mount, the function of which is to couple the r-f energy to it. Bolometer mounts must be specially designed for particular applications, and in microwave measurements they are composed of waveguide elements. The mount matches the impedance of the bolometer to that of the source; and in measurements involving large amounts of power, they are used in conjunction with directional couplers and attenuators which reduce the energy applied to the bolometer to suitable levels.

The bolometer bridge circuit is a special form of the Wheatstone bridge discussed in chapters 5 and 16, *Basic Electricity*, NavPers 10086. It can be used for measurements in different systems and is often supplied in test-set form, an example of which is given in figure 14–13. The figure shows the front-panel appearance of Test Set TS-147/UP, which contains a bridge of the balanced type described in this section.

Bolometers (as stated in chapter 9 of this course) are of two major kinds: barretters and thermistors. Barretters are normal resistive elements with positive temperature co-

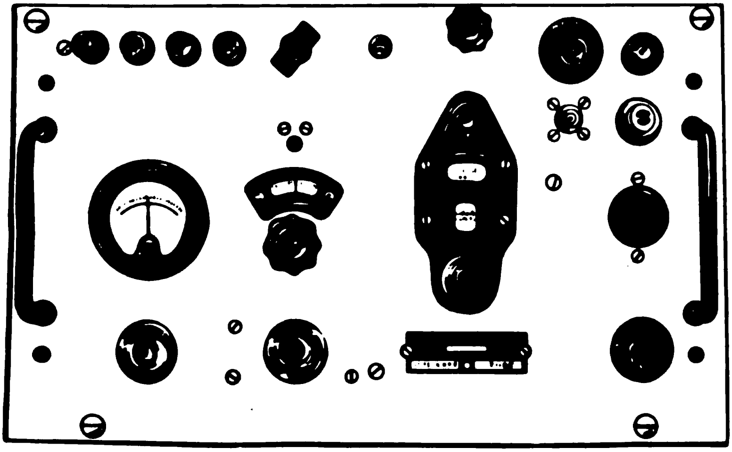


Figure 14–13.—Test Set TS–147/UP.

efficients; that is, the resistance values increase with increases in temperature. In simplest form they consist of short lengths of wire; and most have the desirable characteristic of operating effectively at comparatively high temperatures.

Thermistors are composed of metallic oxides. They have negative temperature coefficients (decreasing resistance with increasing temperature) of large value and may easily vary from 50 to 100 ohms for each milliwatt change in applied r-f power. Compared with barretters, thermistors have the disadvantage of operating at fairly low temperatures; hence, they are more subject to errors due to changes in surrounding temperature. As a result, instruments containing them must usually be compensated for ambient temperature variations.

Thermistor Types.—There are two basic types of thermistors, both of which are used in the TS–147/UP. These are the bead type, illustrated in (A) of figure 14–14, and the disk type, shown in (B). The former consists of a semiconducting material mounted between two platinum-iridium wires and enclosed in a glass envelope. The semiconductor is generally a combination of the oxides of manganese and

of nickel, to which a small amount of copper is added to increase the conductivity. Bead thermistors are frequently used as power-sensitive elements in microwave measurements. They are very small in size and do not give rise to large skin-effect errors which are present in some r-f thermocouple instruments.

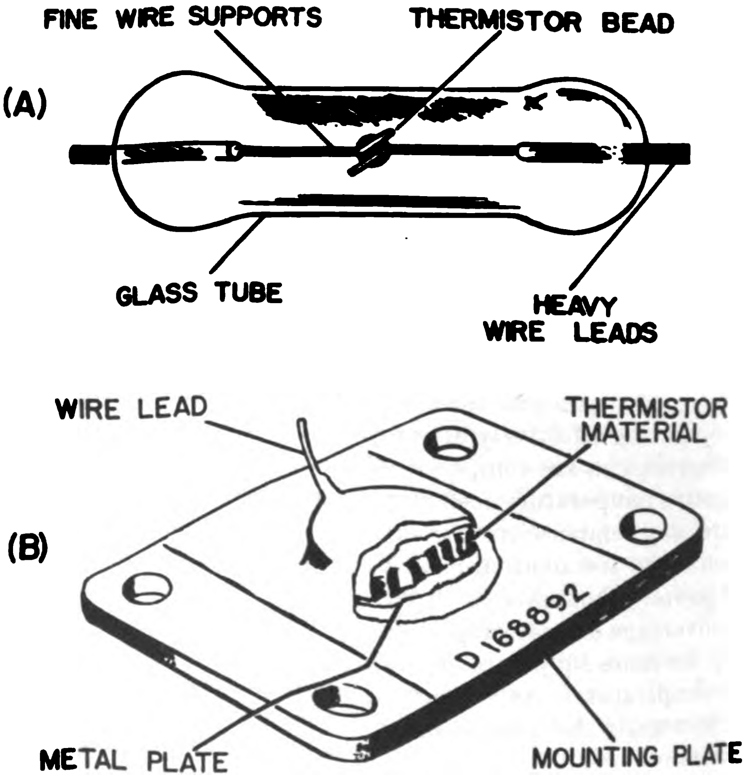


Figure 14–14.—(A) Bead thermistor; (B) disk-type thermistor.

The disk thermistor (fig. 14–14B) has greater volume than the bead type and also more surface area. It is not used as a sensitive element in power measurements but is employed principally as a device for compensating for temperature and drift errors in bridge circuits. The resistance

of the disk thermistor is relatively unaffected by current flowing through it and is dependent mainly upon ambient temperature.

THERMISTOR BRIDGE CIRCUITS.—The bridges used for r-f power measurements are of two fundamental types, each of which has many variations. In the operation of one type, the BALANCED BRIDGE, the circuit is first unbalanced and is then brought into electrical balance by application of the r-f power. The value of the power is determined from the adjustments required to achieve the balanced condition.

The other type, the UNBALANCED BRIDGE, operates in the opposite manner. The bridge is balanced prior to applying the r-f energy. The amount of unbalance caused by the unknown power is then a measure of its value, which is usually read directly on a calibrated meter in the bridge circuit.

A source of variable control power is required with both types of bridges to set up the necessary initial conditions of balance or unbalance. This may be a battery equipped with a potentiometer or else a combination of a battery and a low-frequency, a-c supply.

The principle of balanced-bridge measurements can be illustrated by the circuit shown in figure 14–15. The bridge is composed of three fixed resistors and the variable-resistance thermistor. It is first unbalanced by a fixed amount when d-c power is applied through potentiometer $R123$. The amount of unbalance is such that exactly 1 milliwatt of r-f power must be applied to the thermistor to balance the bridge. The unknown power is then applied through calibrated attenuators, which are adjusted until the bridge is brought into balance. The value of the unknown power is determined from the amount of attenuation necessary to reduce it to the reference value of 1 milliwatt.

The bridge circuit (fig. 14–15) is balanced when the resistance of the thermistor meets the following condition:

$$\text{Thermistor resistance} = R115 \times \frac{R119}{R116}$$

In this condition the current flow in the meter is zero, indicated by the pointer in the center-scale position of the dial marked SET POWER.

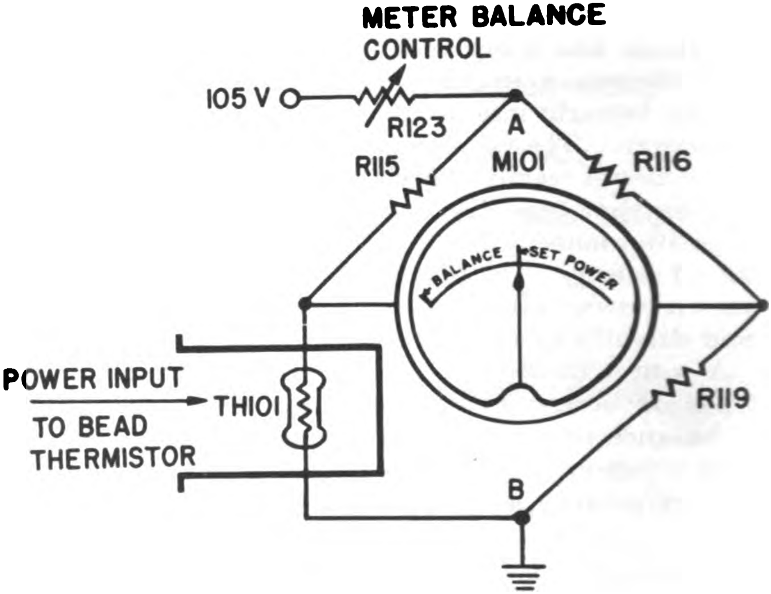


Figure 14–15.—Simplified balanced bridge.

Many power-measuring sets used with naval equipment contain thermistor bridges of the unbalanced type, an example of which is given in figure 14–16. The figure shows a typical thermistor mount. In addition, the circuit contains two disk thermistors, *TH–2* and *TH–3*, used to compensate for variations in ambient temperature.

TH–2 provides sensitivity compensation, the effect of which is to maintain the bridge sensitivity constant over a wide range of temperature. *TH–3* is used for zero-drift compensation, which eliminates the need for frequent resetting of the potentiometer which applies the d-c power for initial balance of the bridge. Both types of compensation are employed in most thermistor instruments.

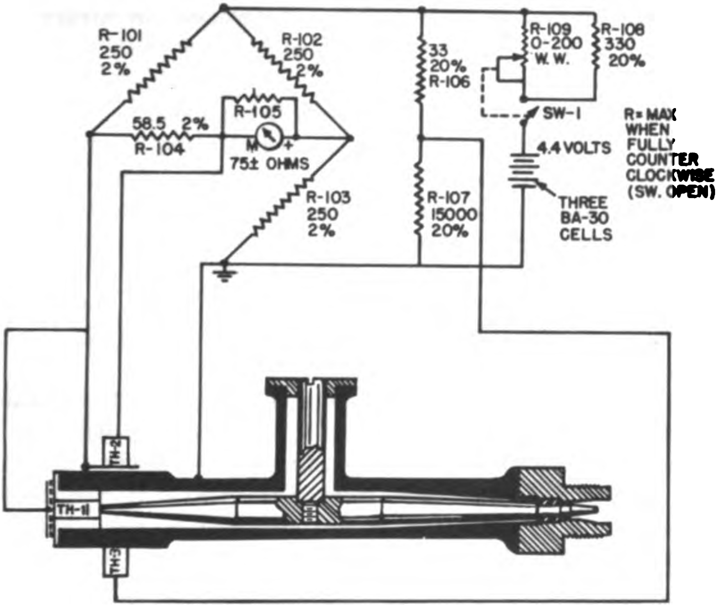


Figure 14–16.—Thermistor bridge: unbalanced type.

The accuracy of power bridges is affected somewhat by frequency. And for this reason it is desirable to make calibration checks and all necessary adjustments with the applied frequency as near as possible to that of the specific equipment to be measured.

Micrometers and Gages

The work of the Guided Missileman involves the use of hand tools of special design as well as standard tools employed in many kinds of measurements. An example of the special-purpose type is the CLINOMETER, an instrument equipped with a leveling device which is used for measuring values of the angle made by a surface and a reference plane. Various kinds of clinometers are employed for checking and

adjusting missile control surfaces such as fins, elevons, trim tabs, and wings. Because of the differences in airframe configurations of different missiles, each of these instruments must be used in accordance with instructions appropriate for the particular measurement involved.

Less specialized measuring tools are also required in the everyday duties of the missileman. At various times modifications of missile units and assemblies must be made; and the layouts must conform exactly with specifications given in the prints or drawing accompanying the modification orders. Among the measuring tools used in most cases is the ordinary decimal rule; while vernier calipers may be required for more precise measurements.

Thickness gages are needed for many adjustments made in hydraulic and pneumatic units. For example, when repairing a hydraulic servo system, this type of tool is necessary for operations such as setting the travel distance of values, which in typical cases are adjusted to values such as 0.005 ± 0.002 inches.

The types and uses of vernier calipers, micrometer calipers, thickness gages, and most of the basic measuring tools used in missile work are discussed in section 1, *Basic Hand Tool Skills*, NavPers 10085. Sections 2, 3, and 4 of the text gives further discussion of measuring tools as well as other standard hand tools the Guided Missileman makes use of at various times.

QUIZ

1. The term HANDLING, when applied to a missile system, refers to the procedures and steps taken with missile components
   a. only when they are being moved or tested
   b. only when being assembled or disassembled
   c. to insure that repairs and changes are properly logged
   d. from original factory delivery through assembly and expenditure of the weapon

2. Handling systems are the result of compromise between which of the following demands?
   a. Security of the missile components
   b. Ease of handling containers
   c. Conformity with ICC, Coast Guard, and Naval safety regulations
   d. All of the above

3. The most important function of a missile container is to
   a. protect the contents from damage
   b. provide ease in handling
   c. meet the requirements of naval safety regulations
   d. maintain standard humidity conditions

4. A desiccant is a
   a. metal preserver
   b. drying agent
   c. special insulation material
   d. dielectric material

5. In most Navy missile systems the systems test equipment is, in effect, used to
   a. isolate individual and malfunctioning parts such as resistors, coils, etc.
   b. simulate flight conditions and check complete missile performance
   c. replace standard test equipment such as oscilloscopes, VTVM's, etc.
   d. check the guidance radar for proper frequency and signal strength

6. When checking a missile unit using a GO-NO-GO test set, if the "NO-GO" result is obtained, lamps on the test set indicate
   a. which stage or stages contain malfunctions
   b. the secondary check points needed to isolate the trouble
   c. how far the circuit response is from being within tolerance
   d. the steps necessary to determine which component of the missile is faulty

7. The test chassis of the system test set described in this chapter controls
   a. itself and the missile
   b. the signal generator chassis and the missile
   c. itself, the signal generator chassis, and the missile
   d. only the missile
8. In the system test set described, which of the following tubes is used by the comparator in the test chassis to indicate the results of comparisons of reference voltages with test voltages?
   a. Velocity modulated tube
   b. Cathode-ray tube
   c. Klystron tube
   d. Thyratron tube
9. The basic pulse frequency of the desired RF output of the signal generator chassis is determined by
   a. the speed of rotation of the FM PULSE WHEEL
   b. the speed of rotation of the AM WHEEL
   c. the phase relationship between the FM PULSE WHEEL and the AM WHEEL
   d. the operating characteristics of a pulse modulated klystron
10. High-resistance shorts between conductors in a cable or in the insulation of a conductor may be detected by use of a/an
    a. ohmmeter
    b. ammeter
    c. VTVM
    d. megger
11. The instrument that is used for displaying graphs of rapidly changing voltage and current as well as for giving information concerning frequencies, phase differences, and voltage amplitudes is the
    a. cathode-ray oscilloscope
    b. spectrum analyzer
    c. vacuum tube voltmeter
    d. absorption tube wavemeter
12. A heterodyne frequency meter can be used as a wavemeter for measuring output frequencies of transmitters and also to
    a. determine the frequency range of a sweeping F-M transmitter
    b. find the center frequency of a modulated carrier signal
    c. determine the amount of r-f energy being radiated
    d. supply accurate test signals of moderate amplitude
13. The FR-38A/U frequency meter, when used to measure a signal frequency,
    a. requires that the incoming signal be periodic in arrival
    b. must have a minimum input signal of one volt

c. can count random output signals of a geiger counter
d. is primarily used in determining the center frequency of an F-M signal

14. The type of wavemeter widely used for the measurement of microwave frequencies is the
a. transmission type
b. reaction type
c. absorption type
d. radiation type

15. Spectrum analyzers are electronic test instruments used to
a. present a visual indication of changing voltage and currents
b. provide a visual indication of the frequency components present in modulated waves
c. determine the amount of r-f energy radiated from a transmitter
d. ascertain the frequency of an unmodulated carrier signal

16. Crystal rectifiers are packaged in metal containers to guard against damage caused by
a. radiation from strong r-f signals
b. excessive heat conditions
c. acid from hands of handling personnel
d. excessive pressures applied to them

17. In determining whether or not a crystal rectifier is acceptable, a comparison is made of the
a. front resistance to crystal current
b. back resistance to front resistance
c. crystal current to test set current
d. reference voltage and crystal voltage

18. R-f power may be measured by means of an instrument containing a heat sensitive element called a
a. galvanometer
b. dynomometer
c. bolometer
d. clinometer

19. Bead thermistors are commonly used
a. to compensate for ambient temperature changes
b. as power-sensitive elements in microwave measurements
c. in compensating for drift errors in bridge circuits
d. because they are relatively unaffected by current flow through them

20. The clinometer is an instrument used for
a. measuring the clearances in control valves and actuators
b. determining the thickness and width of a control surface
c. alining missile rings and fins along the same axis
d. measuring the angle made by a surface and a reference plan

CHAPTER 15

MAINTENANCE AND REPAIR PROCEDURES

The procedures of missile handling and testing and the use of the test equipment described in the preceding chapter represent only a part of the technical duties of the missileman. Of equal importance are those duties included in the fields of maintenance and repair, the basic procedures of which provide the subject matter of this chapter.

It is useful to distinguish between maintenance and repair since these terms have definite meanings when used in naval technical publications, instructions, and notices. The term REPAIR refers to the actions of correcting damage incurred through long use, accident, or other causes. MAINTENANCE is a term representing a very inclusive field, which has several subdivisions. One of these is PREVENTIVE maintenance, or all actions made in systematic steps to reduce or eliminate failures or to prolong the life of equipment. In addition, three other classes of maintenance are recognized: OPERATIONAL; TECHNICAL; and TENDER/YARD, or depot, maintenance.

Operational maintenance consists of inspection, cleaning, servicing, lubrication, adjustment, and preservation of components and assemblies. It also includes the replacement of minor parts when this does not require special skills or necessitate alinement or adjustment as a result of the replacement.

Technical maintenance is limited normally to replacement of unserviceable parts, subassemblies, or assemblies,

followed by alinement, testing, and adjustment of the equipment.

Tender/yard, or depot, maintenance is that which involves major overhaul or complete rebuilding of the principal subassemblies, assemblies, or the total equipment.

In performing any of the types of maintenance and repair listed above the missileman employs knowledge and skills of two fundamental kinds. He must have specific information which pertains only to the particular equipment he may be called upon to repair or maintain. In addition, he must possess and use certain general skills and knowledge which apply to many kinds of equipment and to many types of work assignments.

The specific information required consists of special procedures and processes and detailed, step-by-step directions approved by proper authority and recommended for a particular piece of equipment. This information is supplied by classified publications prepared for the sole use of duly authorized personnel.

The general maintenance skills and procedures are based on knowledge which is not contained in missile publications, but which is presupposed and required as a necessary part of the missileman's professional capabilities. These are the substance of this chapter.

The first section is a brief discussion of the types of publications most useful in missile maintenance and repair. Subsequent sections are devoted to basic procedures in electronic and electrical maintenance and repair; to the essential operations in the maintenance of hydraulic and pneumatic systems; and to the logs, records, and reports required in the work of the missileman.

MAINTENANCE PUBLICATIONS

The primary technical duties of the Guided Missileman include the maintenance of special test equipment as well as the assembly, adjustment, maintenance, and testing of guided missile systems and components. In the performance

of these duties he is assigned and guided by several types of publications. Among the more important of these are the handbooks written for each missile system and for each series of test equipment. These have been referred to frequently in earlier chapters. These handbooks provide the required information concerning the details of the equipment to which they apply and supply the approved and recommended procedures for repair and maintenance.

MISSILE HANDBOOKS

For each system one or more handbooks or manuals is prepared under the direction of the bureau concerned with the development of the system. Handbooks developed by different bureaus may differ somewhat as to arrangement; but in general, the organization of the contents of most is substantially the same. As an example consider a guided missile operation and maintenance publication published under the authority of the Chief of the Bureau of Ordnance. This handbook may be published in two volumes and could contain the following major subdivisions:

Volume 1

SECTION 1 PHYSICAL DESCRIPTION.—This section supplies information as to the purpose for which the missile is used; the purposes of the various kinds of equipment supplied; a complete physical description of the missile; and a list of additional reference publications concerning the missile.

SECTION 2 FUNCTIONAL DESCRIPTION.—In this section the theory of operation of the missile is given in general terms with a detailed functional description of the missile systems.

SECTION 3 MISSILE HANDLING.—A complete description of missile containers; handling equipment; and the procedures for unpacking, as well as assembly and packing procedures are contained in this section.

SECTION 4 REPLACEMENT OF COMPONENTS.—This section contains the authorized procedures for the replacement of faulty components of the missile.

Volume 2

SECTION 5 SUPPLEMENTARY DATA.—This section contains such items as parts lists, safety precautions and schematic diagrams.

SECTION 6 MISSILE SERVICING.—This section describes all the allowable servicing procedures, such as hydraulic system charging procedures, pneumatic charging procedures, electronic adjustments and other procedures to be carried out after the missile has been assembled.

SECTION 7 MISSILE SYSTEMS TEST AND FAULT ISOLATION.—This chapter contains the complete information for performing Missile Systems Tests (MST's) along with data reduction and fault isolation procedures.

In addition to the handbooks of the type described above, the Guided Missileman frequently has occasion to use publications of an entirely different sort. These are publications indexes, which are prepared to assist in procuring written materials of various kinds. The indexes of primary value for the missileman are those which list ordnance and aeronautical publications.

Index of Ordnance Publications

The *Index of Ordnance Publications*, OP–O, is a consolidated listing of all publications and forms which pertain to ordnance activities. It is divided into two parts:

Part I. A numerical listing of all BuOrd publications.

Part II. A listing of all available ordnance publications arranged by subject matter.

Complete information for ordering all the publications listed are included in the *Index*.

Naval Aeronautic Publications Index

The *Naval Aeronautic Publications Index* is a consolidated listing of all publications and forms which pertain to aeronautical activities. It is divided into the following three parts:

Part I. A numerical listing of all effective BuAer publications.

Part II. A table of publications relating to aircraft and equipment.

Part III. A cross reference listing publications applicable to each aircraft and its component equipment.

Complete instructions for ordering all the publications listed are included in the *Index.* It is issued annually and revisions are published at regular intervals during the year.

ELECTRICAL AND ELECTRONIC MAINTENANCE AND REPAIR

Normally, the greater part of the missileman's maintenance and repair work is done with electrical and electronic equipment. Among the basic procedures required are those of (1) troubleshooting, or locating defective stages and part; (2) making connections, both soldered and solderless; (3) replacing parts such as vacuum tubes, resistors, and capacitors; and (4) routine maintenance of switches, relays, and rotating electrical equipment such as generators and dynamotors. Following are some details regarding these.

Signal Tracing Methods in Troubleshooting

The approved procedure for locating trouble in any particular electronic or electrical unit is given in the corresponding handbook and must be followed in detail. A method employed in many cases is signal tracing. This general procedure is very useful for servicing equipment which contains no built-in meters and can be effectively applied to many kinds of missile components.

In signal tracing a voltage similar to the normal incoming signal of the circuit in question is taken from a test instrument, such as a signal generator, and applied to the input terminals. The signals resulting are then checked at various points in the circuit, using test instruments such as vacuum-tube voltmeters, oscilloscopes, or any high-impedance instruments which may be suitable. (In most

cases, the instrument is connected in parallel with some element of the circuit, and hence should present high impedance at the input to minimize any changes it introduces in the circuit operation.) The signals appearing at the check points are then compared with known, standard signals normal for these points so that the stage or section failing to produce the expected signal can be determined, thereby localizing the fault to a particular section of the equipment.

By signal tracing methods the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any other abnormal effect can be detected.

Many missile handbooks prescribe a method of troubleshooting based on the observation of waveforms with a cathode-ray oscilloscope for locating defective stages and parts in missile receivers or amplifiers. As an example, consider the following description of the procedure given by the handbook of a beam-rider missile for troubleshooting a plug-in component consisting of several stages of video amplifiers.

The purpose of the video component is to increase the voltage of the missile guidance pulses to usable levels; and in the process, each stage contributes some desirable characteristic in any pulse it amplifies. The special component test equipment of the missile system is used to supply power for the unit under test and also to supply the input test signals.

The video component is attached to the test set by means of the cables provided and power is applied in accordance with the instructions in the publication. The input pulses are observed with a properly calibrated oscilloscope and the pulse amplitude is adjusted to the exact value prescribed. Calibration of the oscilloscope is done in accordance with the detailed instructions of the handbook so that the instrument indicates the voltage, or amplitude, of the signals and also the pulse width and pulse spacing in microseconds.

The output pulses of each of the video amplifiers are then observed by attaching the oscilloscope input to the test points specified. The characteristics and waveforms normal for each point are given in the handbook, and the observed signals are compared with those required. If at any point the amplitude, pulse width, pulse spacing, or the waveform is incorrect, the parts of the corresponding stage are tested further to determine the cause of the malfunction. These tests may consist of voltage measurements, resistance measurements, or both, to locate the exact part at fault.

A fundamental skill involved in the repair of circuit defects isolated by signal tracing and other troubleshooting methods is that of making electrical connections in conductors.

Soldering

Soldering is the basic method of making low-resistance connections in electronic and electrical circuits. And although considerable progress has been made in the development of solderless connectors, millions of solder joints are produced each year. Properly soldered connections have a high degree of reliability; but as in any product of mechanical processes, the quality may vary widely; and enough poor soldering exists to constitute a major cause of equipment failure. The main requirements for good soldering are proper materials and correct techniques.

MATERIALS.—Solder is a metallic alloy which when melted can be used to join the surfaces of metals by fusing with them. Soft solders are those which melt at low temperatures. Hard solders are alloys with higher melting points—usually red heats.

Soft solder, an alloy of tin and lead, is used almost universally for soldering in electronic circuits. It is specified by giving the percentage of each constituent, with that of tin appearing first. For example, the solder most frequently used with naval electronic equipment is 60–40 solder, which contains 60 percent tin and 40 percent lead.

An important consideration when using solder is the melting point with respect to that of the wires soldered. The melting point of the soft solder mentioned above is 361° F. It can be used only with materials which melt at temperature above this value. Also, it is necessary that joints fused with soft solder are not subjected to temperatures in excess of this figure in the normal operation of the circuits containing them.

A hard solder is required for connections made in equipment where temperatures are high. In its usual form hard solder is a silver alloy with a melting point of approximately 1,175° F.

The effectiveness of the soldering process is aided by the use of a suitable FLUX, which may be defined as any material used on the surfaces to be fused to free them from oxides. The only flux fully acceptable for electronic work is rosin. A core of rosin is contained in most soft solders. The solder is formed by extrusion, being made as a hollow wire with the rosin flux contained as the core. The flux generally used with hard solder is borax mixed with water to a pastelike consistency.

SOLDERING IRONS.—Wires are soldered to contacts or terminals by use of soldering irons, torches, or resistance heating methods. The tool most frequently used in electronic soldering is the electric soldering iron, of which there are many types and styles. Electric irons are rated according to the quantity of heat dissipated by the heating element, with this value ranging from about 25 watts in small pencil-type irons to several hundred watts in the heavy-duty varieties. Connections requiring hard solder are made by the use of torches or by resistance heating.

The selection of an iron of the proper size or heat capacity for a particular job is of considerable importance. One with excessive power dissipation is likely to burn the insulation of the wire or to melt the insert of a connector. On the other hand, too little heat capacity may result in a "cold" solder joint in which the solder does not alloy with

the wire and the contact, thereby providing a poor electrical connection. Table 15–1 gives the approximate ratings of irons suitable for soldering wires of the sizes often encountered in electrical and electronic work.

TABLE 15–1.—WATTAGE RATINGS OF SOLDERING FOR VARIOUS WIRE SIZES

Wire size (AN gage)	*Soldering iron (heat capacity)*
20–16	65 watts.
14 & 12	100 watts.
10 & 8	200 watts.

When choosing an iron for a particular job, you should consider the shape of the tip to be sure that it will provide good heat transfer to the work surface. A fairly large contact area is desirable since it aids in producing a good connection quickly.

If the tip is made of copper, the contact areas can be reshaped and smoothed, if they are pitted, by using a small flat file. Some soldering tips are coated with a layer of pure iron to resist oxidation; these should never be ground or filed.

SOLDERING TECHNIQUES.—After selecting an iron of the proper size and shape, the preliminary step in soldering is preparing the wire and the tip. Consider, as an example, the preparation of a copper wire before soldering it to a connector.

Enough insulation is stripped from the end of the wire to allow about 1/32-inch clearance between the remaining insulation and the connector cup when the wire is placed firmly into the connector. The soldering tip is then tinned by coating it with a thin layer of solder. The tip should be clean and bright; and while the iron is heating, rosin-core solder (60–40) is rubbed on the surface of the tip. It is considered good practice to tin only one surface of the working area so that parts of wires adjacent to those being soldered are not coated by accident. When applying solder

to the heating tip, hold the iron so that the tinned surface is turned away from your face.

The wire is tinned by holding the iron tip and the solder together on the wire until the solder begins to flow. The iron is then moved on the opposite side of the wire; and approximately one-half of the exposed length is tinned or covered. The tinning operation, illustrated in figure 15–1, is complete when the sides and ends of the wire strands are fused together with a coat of solder, and the wire is then ready to be joined to the connector.

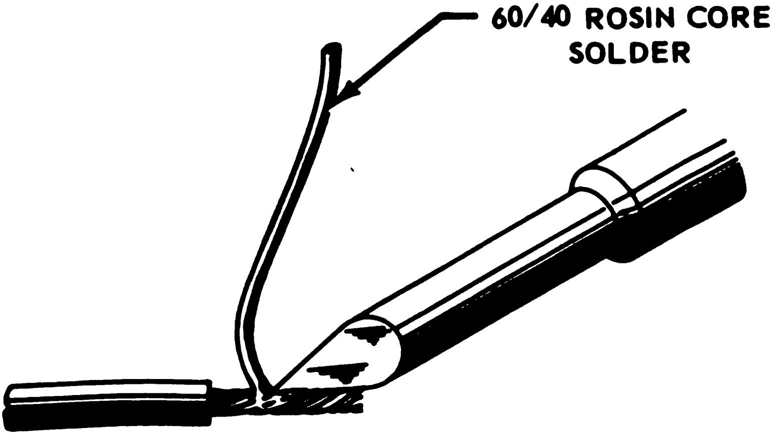


Figure 15–1.—Soldering iron tinning.

In appearance, a well-bonded solder connection is clean and bright, and it approximately outlines the wire as shown in figure 15–2. If the surfaces of the work are perfectly clean and well tinned, the molten solder flows evenly and adheres firmly without piling up in thick layers. The insulation near a well-made joint is free of nicks and is not charred or covered with rosin flux. The end of the insulation should be near but not in the opening of any terminal lug or connector to which the lead is soldered; and the finished joint should be perfectly free from enamel particles

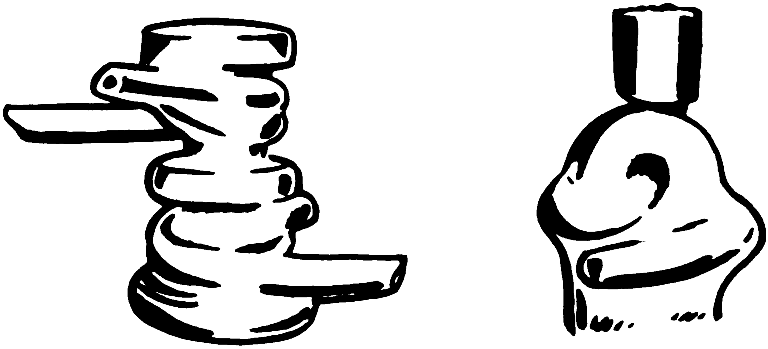


Figure 15—2.—Properly made solder connections.

or any other impurities which are sometimes trapped in molten solder.

A thin film of rosin may remain on the metal surface of the completed joint; this need not be removed unless the connection is in a high-frequency circuit or unless it is anticipated that the equipment will be fungus proofed. If it is necessary to remove residues of rosin, this can be done by applying Stoddard's Solvent (available through naval supply channels) with a stiff brush followed by drying using compressed air.

All persons skilled in soldering know that good connections result only from clean parts, careful soldering technique, and proper preparation of the work. The following general rules apply to most of the soldering in electronic or electrical maintenance:

1. Extra amounts of heat and special fluxes can never serve as substitutes for clean soldering surfaces.

2. Use rosin only as a flux when soldering electrical conductors. Never use an acid-core solder.

3. Joints with thick layers of solder are likely to be porous or cold connections. Use only enough solder to make a clean, neat joint.

4. Solder has very little mechanical strength and should never be depended upon to keep connections from pulling

apart. Use a cable clamp, or wrap the lead about a terminal to give the required mechanical strength.

5. Care should be taken to avoid moving the connection before the solder has hardened.

6. Safe and acceptable connections cannot result if the wires are not properly tinned.

Soldering Miniature Parts.—The Guided Missileman must exercise considerable care when soldering leads in missile components that contain miniature tubes and parts. Many small resistors, capacitors, connecting wires, and other electronic parts are placed in close proximity in most subassemblies; and while soldering one part, it is very easy to damage those parts nearby. In the preparation of the work for soldering it is necessary to use tools of correct size. Small jeweler's pliers and side cutters are available through supply channels and should be used when working on miniature subassemblies. Large hand tools present a hazard in this work and their use should be avoided.

Soldering irons should have wattage ratings high enough to provide enough heat for making good connections but not so large as to cause overheating and damage to adjacent parts. A pencil-type iron with a tip small enough to work in confined spaces is generally preferable for work with missile components though many connections such as those made to ground terminals must be made with an iron of larger capacity.

Overheating and damage to miniature resistors and capacitors can be avoided only by restricting the conduction of heat to the metal leads and preventing it from flowing into the body or the part. This can be done by means of a thermal shunt, which operates in much the same way as a shunt on a sensitive current meter used in a circuit carrying heavy current. A simple and frequently used method of providing a thermal shunt is to grip the lead between the body of the miniature part and the terminal with a pair of long-nose pliers. The metal jaws form a low-resistance heat path which bypasses the flow of heat around the part. This

method has certain disadvantages since it is awkward to solder with one hand; and also, the operator may have a tendency to release the pliers upon removing the iron and permit an unrestricted flow of heat into the part from the still molten joint. Also, steel pliers do not possess the degree of heat conductivity required for effective shunting or full protection against damage.

A much more effective heat shunt is provided by a clamp made of copper and which can be left attached to the lead until the joint cools. A good clamp shunt can be made easily by sweating small copper bars into the jaws of an ordinary alligator clip. A shunt of this type is shown in figure 15–3.

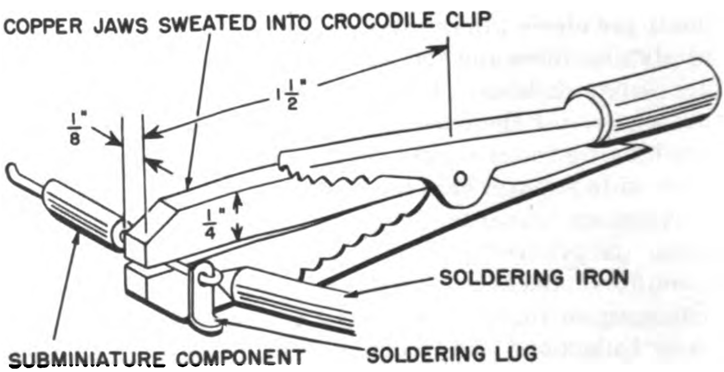


Figure 15–3.—Details of clamp-type heat shunt.

A clamp-type heat shunt should be used when soldering the leads of small capacitors, resistors, choke coils mounted on polystyrene forms, and wire-ended crystals. The clamp should be placed near the body of the part and as far as possible from the joint being soldered. Care should be taken to avoid a low-resistance heat part between the hot soldered connection and the part by allowing the clamp to contact both.

The effectiveness of the heat shunt can be maintained by keeping the jaws flat and free from dirt, grease, or solder-

ing flux so that a good contact between the clamp and the metal lead is insured. The face of the clamp turned toward the iron should be kept bright to minimize heat transfer by radiation, while the rest of the clamp body should be dull black in color.

Solderless Terminations and Splices

Special tools and methods for making cable connections without the use of solder are employed extensively in the aircraft industry and are rapidly coming into use in the fabrication of electrical cables for guided missile systems. The principal kinds of solderless connections are those made for splicing cables and for attaching terminal lugs to cable ends. Solderless splices are often used to join lengths of heavy electrical conductors to form permanent, continuous cable runs. Solderless terminal lugs provide a rapid and efficient means of equipping cables for attachment to terminal blocks, busbars, and to electrical machines.

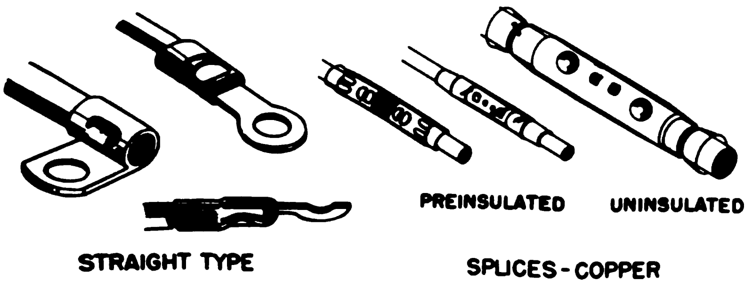


Figure 15–4.—Solderless terminal lugs and splices.

Solderless terminal lugs and splices are made either of copper or of aluminum. They are designed for several kinds of applications and are the PREINSULATED or of the UNINSULATED types. Terminal lugs may be of the straight, flag, or right-angle designs, the first two of which are illustrated in figure 15–4. Examples of copper splicing connectors are also shown in the figure.

Terminal lugs and solderless splices are crimped to the conductors either by means of hand tools or by power tools. (The process is also called "staking" and "swaging.") Hand crimping tools, such as the one shown in figure 15–5, are of the type more frequently used in the work of the Guided Missileman. These tools crimp the barrel of the lug to the conductor; and with preinsulated connectors, they also simultaneously crimp the insulation grip to the insulation of the wire.

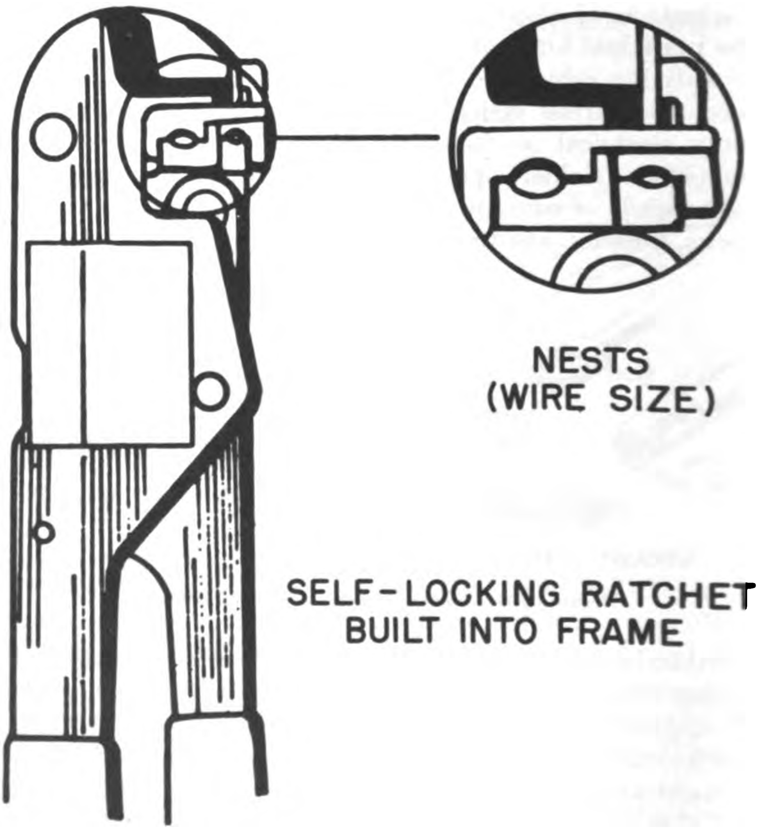


Figure 15–5.—Standard crimping tool, MS 25037.

The preinsulated terminal lug is widely used for terminating smaller sizes of copper conductors. The construction of this type of terminal is shown in figure 15–6 by a cutaway drawing. The insulation forms a part of the lug and extends beyond the barrel, so that upon connection, it covers a portion of the wire insulation and makes the use of an insulation sleeve unnecessary. This type of lug also contains a metal reinforcing sleeve beneath the insulation called an INSULATION GRIP, which provides extra gripping strength and holds the wire insulation firmly.

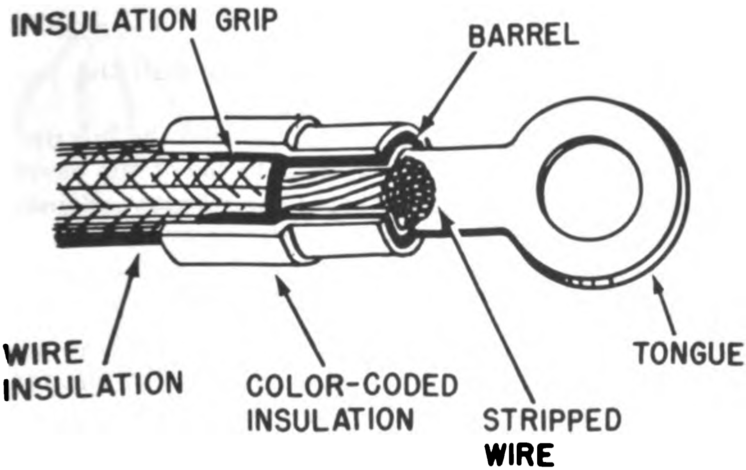


Figure 15–6.—Preinsulated terminal lug: cutaway drawing.

Preinsulated lugs of the type shown (fig. 15–6) are used as terminations for copper conductors of sizes 22 through 10 (AWG). The lugs are color coded to indicate the wire sizes for which they are suitable. Those having red insulation are used to terminate wire sizes 22 through 18; lugs with blue insulation are used for wire sizes 16 and 14; and lugs with yellow insulation are used with wire sizes 12 and 10. The procedure by which the terminal lug is attached can be understood by considering the directions for crimping provided with the MS 25037 Crimping Tool illustrated in figure 15–5.

CRIMPING PROCEDURE FOR PREINSULATED TERMINALS.—Hand crimp the preinsulated copper lugs to wires of the 20–10 size range by the following steps:

1. Strip the wire insulation: sizes 22 through 14 should be stripped $\frac{3}{16}$ inch from the end; sizes 12 and 10 are stripped $\frac{9}{32}$ inch from the end.

2. Check the tool for correct adjustment. (Tool MS 25037 is checked when fully closed. A size 36 drill rod should not be able to enter the smaller nest. If the tool is out of adjustment, it should be returned for repair.)

3. Insert the terminal lug tongue first into the crimping jaws until the barrel of the lug butts flush against the tool stop.

4. Squeeze the handles of the tool slowly until the jaws hold the lug firmly but without denting it.

5. Insert the stripped wire into the barrel of the lug until the wire insulation butts flush against the end of the barrel. Squeeze the tool handle until the ratchet releases. Remove the completed assembly and examine for proper crimp.

Replacement of Subminiature Tubes

The replacement of subminiature tubes in missile electronic components is a typical job in the work of the GF. This job involves several kinds of specialized knowledge and skills, among which are the proper method of identifying the tube leads, specialized soldering techniques, the use of parts layout diagrams, the interpretation of schematic wiring diagrams, and the submission of failure reports.

In (A) of figure 15–7 a subminiature tube is shown full size. The tube elements are not connected to rigid pins on the base as in a standard tube; but as shown in the drawing are brought out from the envelope in the form of flexible leads. This method of construction makes tube replacement more of a problem than in the case of the ordinary vacuum tube which is usually slipped into a socket-type mounting.

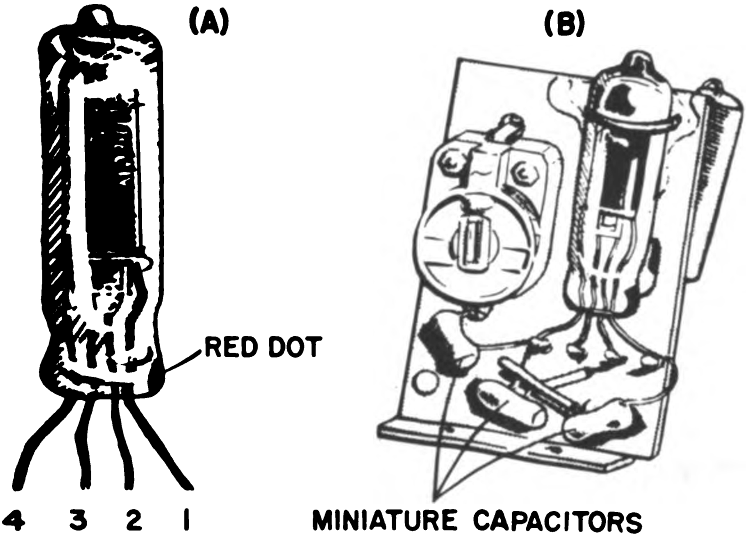


Figure 15–7.—(A) Subminiature tube; (B) component subassembly.

The method by which subminiature tubes are mounted is indicated in (B) of figure 15–7, which shows the tube placed in a metal spring-type clamp in a typical component subassembly.

LEAD IDENTIFICATION.—The leads of the subminiature tube are usually identified by means of a colored dot (often red) placed on one side of the tube base to serve as a reference mark. The lead nearest the dot is lead number one; the lead adjacent is number two; the next is number three, and so on. In some cases a blank space is encountered which would normally be occupied by a lead. When this occurs, the space is counted as if a lead were present. Once each lead has been identified with a number, the tube element to which a given lead is attached can be found by consulting the schematic diagram of the circuit containing the tube.

REPLACEMENT.—When replacing a faulty subminiature tube in a missile circuit, the first step is to unsolder the leads of the bad tube from the terminals to which they are nor-

mally attached. A heat shunt is used when necessary to protect miniature parts connected to the same terminals as the tube leads. The tube is then removed from the tube clamp.

The new tube is inserted carefully in the clamp, orienting the red dot on the base to the same position as the one on the base of the tube which was removed. If the dot on the faulty tube is obliterated, or if its position is in doubt, the correct position of the new tube can be determined by referring to the appropriate parts layout diagram in the missile maintenance publication.

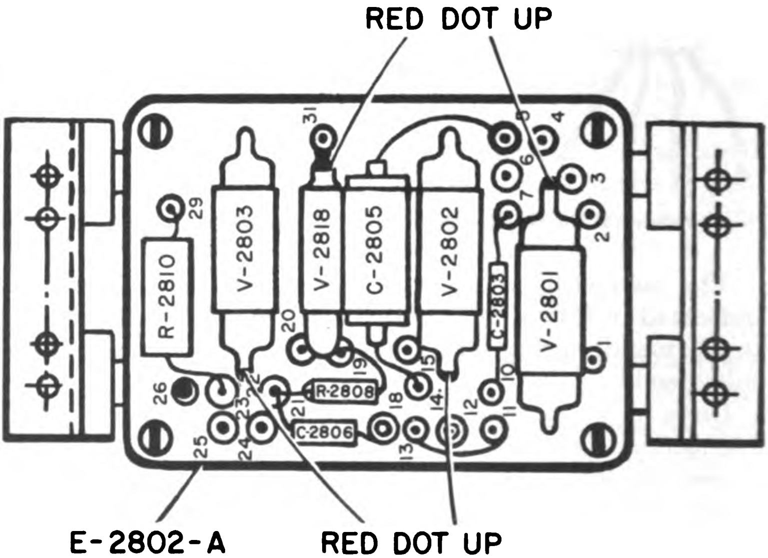


Figure 15–8.—Component subassembly parts layout diagram.

A complete missile component is composed of several subassemblies; and for each there is a parts layout diagram in the maintenance handbook. An example is given in figure 15–8, which illustrates the physical locations of four tubes, two resistors, and three capacitors, all of which are included in the subassembly shown. A diagram of this type gives information concerning the placement of the various

parts and also data pertaining to the tube leads. In the drawing, the identifying dot on each tube is indicated and the solder terminals are shown as small circles, identified by number. Also, a subassembly number, E–2802–A in this example, is given which serves to identify the subassembly on the complete component wiring diagram and on the component schematic diagram.

After the position of the tube has been determined from the layout drawing, the component wiring diagram can be used to determine how the tube leads should be soldered. Unlike the parts layout, the wiring diagram does not show the physical placement of the parts, but indicates the electrical connections between various parts and subassemblies. An example is shown in figure 15–9, a wiring diagram of subassembly E–2802–A. In this diagram the same parts appear that are included in the parts layout given above.

If, for example, V 2801 is the tube to be replaced, it can be seen from the wiring diagram (fig. 15–9) that lead number 1 of the tube is to be connected to solder terminal number 7. Lead number 2 of the tube attaches to terminal number 6; lead number 3 to terminal number 4; lead number 4 to terminal number 5; leads 5 and 6 of the tube to terminal number 3; and lead number 7 is to be connected to terminal number 2.

Prior to making the connections, the tube leads, which are bare of insulation, must be covered with a suitable insulating material. This is generally done by the use of small-diameter insulating sleeving placed over each tube lead. After first determining the length of the leads, a piece of sleeving about ⅛ inch shorter than the lead is slipped over each wire and seated firmly against the tube base. The solder connections can then be completed; and again extreme care should be exercised in making the connection, and a thermal shunt should be used again if necessary to protect nearby parts. After replacement of the tube, it is necessary to fill out a failure report concerning it.

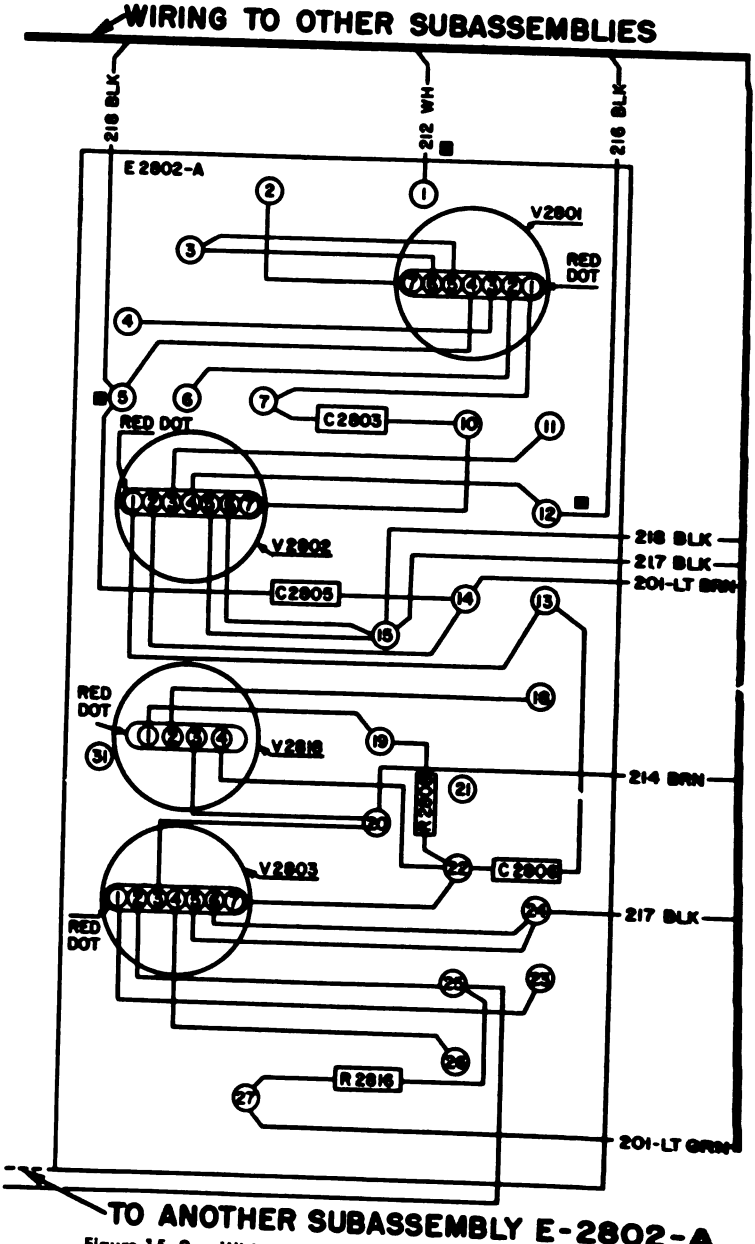


Figure 15–9.—Wiring diagram of subassembly E–2802–A.

Replacement of Parts

The *Illustrated Parts Breakdown* handbook issued with each missile, together with the maintenance publications pertaining to the missile test equipment, provide detailed information on all the parts used in the units. In the Introduction of the *Illustrated Parts Breakdown* there is a section with the heading "Ordering Spare Parts" which reads as follows:

> "Each Service using the *Illustrated Parts Breakdown* has established certain depots and service groups for the storage and issuance of required spare parts to its organizations. The regulations of each Service should be studied to determine the method and source for requisitioning repair parts. The information given in this breakdown regarding a contractor's or manufacturer's name, or the type, model, part, or drawing number of any part, if not to be interpreted as authorization to field agencies to attempt to purchase identical or comparable parts directly from the manufacturer, or from a wholesale or retail store, except under emergency conditions, as covered by existing regulations of the Service concerned. . . .
>
> "If a JAN or AN standard part number is given to a part, only a JAN or AN standard part should be used as a replacement. If no JAN or AN standard part number is given, care should be taken in the choice of a replacement part other than that listed. . . . Parts not assigned a JAN or AN standard part number are special parts, probably chosen for a quality not available in standard parts, and the use of standard parts for replacement purposes may result in decreased equipment life or substandard performance."

In view of this requirement for exactness in parts replacement, it is necessary that the Guided Missileman know the sources of information concerning the selection of parts and that he be familiar with standard designations. To illustrate the data given, consider the following example taken from the entries in the component parts list of the handbook quoted:

R–713; 5905–249–4239; RESISTOR, fixed, composition, 24,000 ohms $\pm 5\%$; 2w.

RC 42GF243J

JAN Designation

466247 O—58——27

The first entry, R-713, is the reference symbol which serves to identify the part with respect to the schematic diagram of the equipment.

The second group is the stock number of the part. This is followed by the part description, which supplies several items of information. These include the name and type of construction; the value of the part in the appropriate unit (such as ohms for resistors); the tolerance, or possible variation from the rated value; and in the case of resistors, the wattage rating. (In addition to the description, some handbooks also give the function of the part in the equipment.)

Associated with each part listed is an entry called the "Source Code." These symbols give information concerning (1) the source of supply, that is, whether the part is to be procured from supply sources, manufactured by the using activity, manufactured by an O and R Department, or obtained from salvage; (2) the level at which the item may be requisitioned and installed; and (3) the action to be taken as to salvage and repair of the part when defective.

Immediately below the description of the part is a symbol which is either a JAN designation, an AN number, or a manufacturer's part number. Parts which are frequently replaced, such as tubes, resistors, and capacitors, usually have JAN designations. The interpretations of these symbols as applied to fixed resistors and capacitors are given in the following section.

JAN Designations and Color Codes for Resistors and Capacitors

Type designations consisting of combinations of letters and numbers are used to identify JAN resistors and capacitors. These designations indicate, in accordance with a code, the important electrical and physical characteristics of the part to which they refer. Where limitations of space do not permit the type designation to be marked on the part, color coding is employed to indicate the electrical characteristics. The color markings consist of colored dots, col-

ored bands, or combinations of bands and dots. A summary of the system of designating fixed resistors and fixed capacitors, including the various color codes is given below.

Fixed Composition Resistors.—The JAN designation for fixed composition resistors may be illustrated by means of the resistor mentioned in the preceding section. The designation is made up of five parts:

RC	42	GS	243	J
(a)	(b)	(c)	(d)	(e)

(a) Component. The first is the component designation, which consists of the letters RC. The letter R stands for "resistor" and the letter C indicates the subclass "composition."

(b) Style. This style is indicated by a two-digit number which refers to the power rating, physical shape, and size.

(c) Characteristics. A two-letter group, GS in the example above, gives the characteristics of the resistor. The first letter denotes whether the element is insulated and also its moisture resistance. The second letter designates the resistance-temperature characteristics. (The interpretations of the symbols for style and characteristics can be found in JAN–R–11.)

(d) Resistance value. This part of the designation is a three-digit number indicating the resistance value in ohms. The first two digits are the first two figures of the resistance value, and the final digit gives the number of zeros which follow the first two figures. In the example, the value is 24,000 ohms since the (d) part of the designator is 243.

(e) Resistance tolerance. The final part of the designator is a single letter which corresponds to a percentage figure preceded by a "plus-or-minus" symbol. The percentage figure expresses the tolerance, or the amount by which the actual value may differ from the resistance value stated. The letters used and the corresponding percentage figures are given in the following list:

Letter	*Tolerance*
J	±5%
K	±10%
M	±20%

RESISTOR COLOR CODES.—Fixed composition resistors are marked by color coding to indicate the resistance value and the resistance tolerance. As shown in the sketches in figure 15–10, these values may be given either by the position and color of bands or by the body color, end color, and dot color.

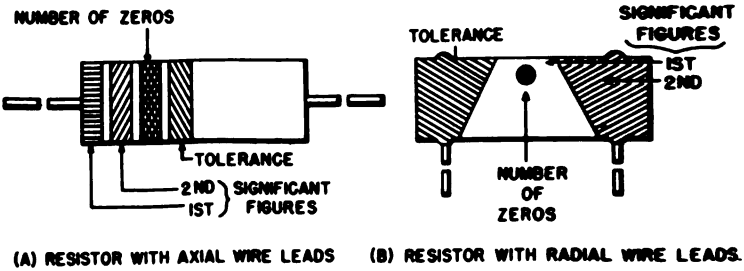


Figure 15–10.—Color code for fixed resistors.

The colors are associated with the values shown in table 15–2. Consider as an example an axial-lead resistor with bands colored red, orange, yellow, and gold, reading from left to right. The red band signifies a first digit of 2 for the resistance. The orange band shows a second digit to be 3. The yellow band signifying 4 means four zeros are to be added to the first two digits, giving a resistance of 230,000 ohms. The gold band is the tolerance indication and means ±5 percent.

As an example of the color code applied to a radical-lead resistor, suppose there is a body color of orange, an end color of blue, and a green dot, and an end color of silver. The interpretation is as follows:

The orange body signifies a first digit of 3.
The blue end signifies a second digit of 6.
The green dot means 5 zeros are to be added.
The silver end indicates a tolerance of ± 10 percent.
The resistance value is then 3,600,000 ohms, ±10 percent.

TABLE 15-2.—RESISTOR COLOR CODES

Body—first band		End—second band		Dot—third band		End—end band	
Color	Value	Color	Value	Color	Value	Color	Tolerance
Black	0	Black	0	Gold	0.1	Gold	(J) ± 5%
Brown	1	Brown	1	Silver	0.01	Silver	(K) ± 10%
Red	2	Red	2	Black	None	None	(M) ± 20%
Orange	3	Orange	3	Brown	0		
Yellow	4	Yellow	4	Red	00		
Green	5	Green	5	Orange	000		
Blue	6	Blue	6	Yellow	0000		
Violet	7	Violet	7	Green	00000		
Gray	8	Gray	8	Blue	000000		
White	9	White	9	Violet	0000000		
				Gray	00000000		
				White	000000000		

FIXED MICA CAPACITORS.—The JAN designation system for fixed mica capacitors may be illustrated by the following example:

CM	20	A	050	M
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT.—All fixed mica-dielectric capacitors represented by the JAN type of designation are represented by the letter CM as the first two symbols of the designator.

(b) CASE.—The case designation is a two-digit number which is used to identify the type of case, both in size and shape. (The interpretation of these symbols is given in JAN–C–5.)

(c) CHARACTERISTICS.—The characteristics symbol is a single letter which refers to the temperature coefficient and to the maximum capacitance drift.

(d) CAPACITANCE VALUE.—The value of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first digits of the capacitance value. The final digit specifies the number of zeros which follow the first two digits.

(e) CAPACITANCE TOLERANCE.—The tolerance, expressed as a percentage figure preceded by a plus-or-minus sign is designated by a letter from the following list:

Designation letter	*Tolerance*
G	±2%
J	±5%
K	±10%
M	±20%

The color code for JAN mica capacitors is shown in figure 15–11. The colors are interpreted as in table 15–3.

The letters in the column headed "Characteristics" in table 15–3 have the following meanings:

A—Ordinary mica bypass capacitor.

B—Similar to A but with a low-loss case.

C—Bypass or silver mica (temperature coefficient of ±200 parts per million per degree C.).

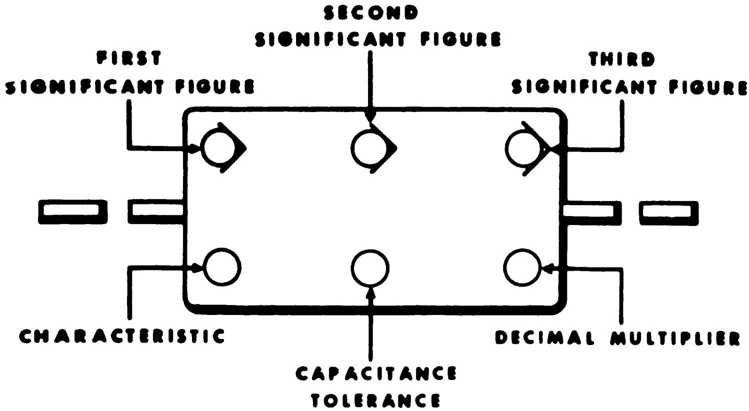


Figure 15–11.—Color code for fixed mica capacitors.

TABLE 15–3.—COLOR CODE FOR MICA CAPACITORS

Capacitance			Tolerance	Character-istics
Color	Significant figure	Decimal multiplier		
Black	0	1	20% (M)	A
Brown	1	10	1%	B
Red	2	100	2% (G)	C
Orange	3	1,000	3%	D
Yellow	4	10,000	4%	E
Green	5	100,000	5%	F
Blue	6	1,000,000	6%	G
Violet	7	10,000,000	7%	
Gray	8	100,000,000	8%	
White	9	1,000,000,000	9%	
Gold	--------	0.1	5% (J)	
Silver	--------	0.01	10% (K)	

D—Silver mica (±100 parts per million per degree C.).
E—Silver mica (0 to 100 parts per million per degree C.).
F—Silver mica (0 to 50 parts per million per degree C.).
G—Silver mica (0 to −50 parts per million per degree C.).

The expression "±200 parts per million per degree C." means that the capacitance may increase or decrease 200 micromicrofarads for each million micromicrofarads in the rated value when the temperature changes by one degree centigrade.

FIX CERAMIC-DIELECTRIC CAPACITORS.—The JAN designations of fixed ceramic-dielectric capacitors indicate the component, the style, the characteristics, the capacitance value, and the capacitance tolerance. The type designation is formed as in the following manner:

CC	25	SL	100	G
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT.—Fixed ceramic capacitors are identified by the symbol, CC. The first letter indicates a capacitor, and the second signifies those capacitors with ceramic dielectrics.

(b) STYLE.—The style designation is a two-digit number which identifies the particular shape and size of the capacitor.

(c) CHARACTERISTICS.—The characteristic designation is a two-letter symbol in which the first letter specifies the temperature coefficient of capacitance, and the second letter indicates the tolerance of the temperature coefficient.

(d) CAPACITANCE VALUE.—The capacitance of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first two digits of the value expressed in the unit mentioned. The final digit specifies the number of zeros which follow the first two digits. When more than two significant figures are required, additional digits may be used, but the last digit always indicates the number of zeros.

(e) CAPACITANCE TOLERANCE.—The capacitance tolerance expressed as a "plus-or-minus" quantity is designated by a letter as shown in table 15–4. Where the indicated value of capacitance is greater than 10 micromicrofarads, the tolerance is expressed in percent. When the value is 10 micromicrofarads or less, the tolerance is expressed in micromicrofarads. The table of tolerance is as follows:

TABLE 15–4.—TABLE OF TOLERANCES FOR CERAMIC-DIELECTRIC CAPACITORS

Letter symbol	Percent	mmfd.
C	--------	0.25
D	--------	.5
F	1	1.0
G	2	2.0
J	5	--------
K	10	--------
M	20	--------

The color code for ceramic capacitors is shown in figure 15–12.

The color code applied to the color bands shown in figure 15–12 is given in table 15–5.

The discussion in this section on the JAN system of designation can be supplemented with additional information contained in *Basic Electronics*, NavPers 10087, Appendix II,

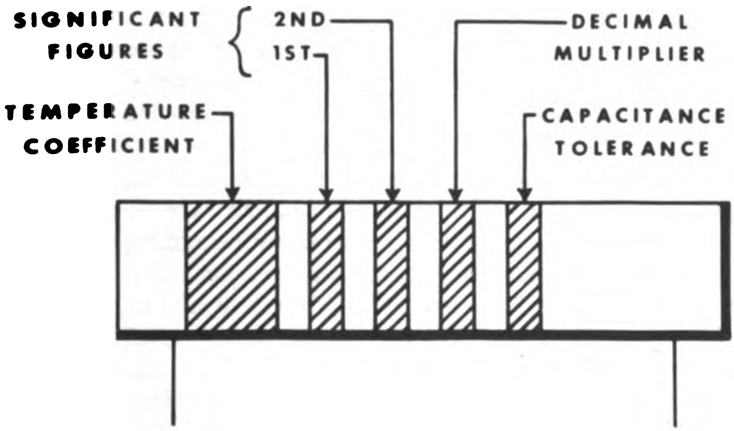


Figure 15–12.—Color code for ceramic capacitors.

TABLE 15–5.—COLOR CODE FOR CERAMIC CAPACITORS

Color	Significant figure	Multiplier	Tolerance of capacitance: Capacitors of value greater than 10 mmfd. in percent	Capacitors of 10 mmfd. or less in mmfd.	Temperature coefficient parts per million per degree, centigrade
Black	0	1	20 (M)	2.0 (G)	0
Brown	1	10	1 (F)		−30
Red	2	100	2 (G)		−80
Orange	3	1, 000			−150
Yellow	4	10, 000			−220
Green	5	100, 000	5 (J)	0.5 (D)	−330
Blue	6	1, 000, 000			−470
Violet	7	10, 000, 000			−750
Gray	8	0. 01		0.25 (C)	+30
White	9	0. 1	10 (K)	1.0 (F)	+550

which contains tables and diagrams pertaining to the RMA system of color coding for resistors, capacitors, and transformers.

Maintenance of Commutators and Sliprings

The commutators and sliprings of rotating power equipment are inspected and cleaned at regular intervals as specified in the *Handbook of Service Instructions* accompanying the equipment.

The motor, dynamotor, or generator is removed in accordance with the instructions. Dust and dirt are cleaned from the machine and from the end covers either with a soft brush or by the use of dry, compressed air.

The electrical brushes are then loosened and carefully removed and inspected. The location and position from which each is taken should be noted so that the brush can be replaced in the correct position upon reassembly.

If the brushes bind in the brush holders, they may be wiped with a clean cloth; and if this does not suffice, they should be thinned down with No. 0000 sandpaper. Care

should be taken to avoid letting the sandpaper touch the contact surfaces of the brushes. The contact edges must not be rounded or chipped, and any loose abrasive or carbon dust should be removed carefully. If the brushes are cracked, damaged, or worn excessively, they must be replaced. When new brushes are installed, the procedure should be in accordance with the instructions for brush seating provided with the specific equipment.

After inspection of the brushes, the commutator is checked for excessive wear, dirt, or any visible defect. If the surfaces are dirty, they should be cleaned with a lint-free cloth moistened with a suitable cleaning solvent. After cleaning, the surfaces must be carefully wiped dry. Care should be taken to avoid fingermarking of the commutator surfaces after cleaning.

A highly polished commutator surface is desirable; although if the surface is darkened, this does not necessarily mean that it is burned. Slight pitting of the commutator can be removed by the use of commutator sticks of pumice grade, followed by polishing with canvas cloth.

When commutators become badly worn or scored, they must be refinished. This operation should be done only by properly qualified personnel and only at a properly equipped repair station.

The sliprings of a-c machines must be inspected periodically for smoothness of the surfaces, proper diameter of the rings, and correct alinement of the rings on the shaft.

In routine maintenance of sliprings, cleaning and polishing is accomplished by using No. 0000 sandpaper or some finer grade. Emery cloth or coarse sandpaper should never be used. After cleaning with sandpaper of the grades suitable, any sand particles which may have collected on the rotor should be blown away with dry compressed air.

Antifriction Bearings

Antifriction bearings may be either of the ball or the roller types, both of which are widely used in rotating electrical equipment. Many modern electrical machines are equipped

with SEALED bearing assemblies. The maintenance of these bearings is very easy, since they are prelubricated and require almost no attention during the normal life of the machine in which they are installed.

As a guide to proper maintenance of ball or roller bearings in rotary equipment, the detailed recommendations of the manufacturer as given in the *Handbook of Service Instructions* should always be followed. As an example of a general maintenance procedure, consider the following directions, which are taken from the manufacturer's instructions pertaining to a small generator containing standard ball bearings.

The bearings used in this generator normally are replaced with new bearings whenever abnormal conditions occur. However, in the event that replacements are not available, the bearings may be cleaned and relubricated as follows:

1. Wipe the outside of the bearings clean, using a clean cloth.

2. Wash the bearing thoroughly in cleaning solution (Specification PS–661).

3. Blow with compressed air until the assembly is dry. Care should be taken not to rotate the bearings while washing or drying.

4. Relubricate by packing the bearing full with General Purpose Lubricating Oil (Military Symbol 2190).

5. With a clean wooden stick, dig out all grease that can be removed from between the balls on both sides of the bearing assembly. This will leave the bearing about 25 percent full of lubricant, which is the maximum that should be used.

When dismantling a machine, the bearings should be removed carefully, wiped clean, and wrapped in clean oil paper until needed during reassembly of the machine.

In the inspection of ball bearings, the assembly is slowly rotated. Bearings showing pronounced stickiness or bumpy operation should be replaced. During inspection of bearing assemblies, check for the presence of cracks, pitted surfaces, and any physical damage present in the bearing elements.

Relays seldom require servicing unless a short circuit has caused the contacts to become burned or pitted, or unless damage has resulted from rough handling or improper treatment. When cleaning or adjusting a relay, it should be handled as if it were an expensive watch or a delicate meter.

Relays can be ruined by the use of sandpaper or emery cloth for cleaning the contacts. A BURNISHING TOOL should be used for this purpose. Two types of burnishing tools are stocked at naval supply activities; and either type can be obtained through regular supply channels. The appearance and use of one kind of burnishing tool are shown in (A) of figure 15–13. The surface of the tools that are used to clean the relay contacts should not be touched by the fingers prior to use; and after use, the burnisher should be cleaned with alcohol.

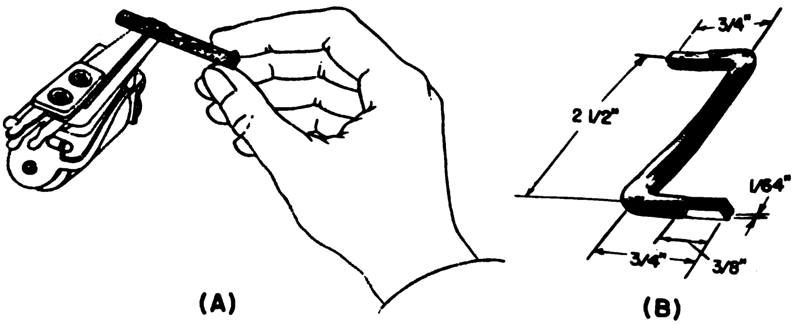


Figure 15–13.—(A) Relay burnishing tool; (B) relay point bender.

When relays contain bent contacts, no attempt should be made to straighten them with long-nose pliers. Such an attempt often causes further damage with the result that the entire relay must be replaced. Bent contacts can be straightened effectively by using a contact bender. The bender can be made locally from 0.125 diameter rod stock according to the dimensions shown in (B) of figure 15–13.

Maintenance of wafer-type switches which are included in many kinds of electronic equipment involves adjustment and cleaning. These operations are accomplished by the same procedures and by use of the same tools employed for relays.

MAINTENANCE OF HYDRAULIC AND PNEUMATIC EQUIPMENT

The maintenance and repair of hydraulic and pneumatic units in missiles and in missile test equipment pose no special problems if the instructions given in the appropriate maintenance publications are followed closely. However, there are two general precautions of importance which apply to work with fluid systems. These are the need for cleanliness in work areas, tools, and in the equipment; and the need for constant observance of safe work practices.

The standard safety precautions applicable to hydraulic and pneumatic maintenance and repair are given in chapter 16 of this course. The need for cleanliness results from the fact that the moving parts of hydraulic and pneumatic devices are machined to very close tolerances and must be perfectly free from foreign matter. The smallest impurity introduced into these systems either from the work area or from tools can damage the precision components, impair the operation of the overall system, and cause a missile failure.

PERIODIC INSPECTIONS.—As aids in preventing impurities from entering missile fluid equipment, inspections are made at regular intervals of the auxiliary test equipments, particularly of those units which supply fluid for testing the missile and which charge it prior to flight.

At intervals specified by maintenance handbooks the input and output filters of the system should be removed and examined. The filters are usually of the micronic type. In these, the elements cannot be cleaned. If these show signs of excessive collection of impurities, they must be replaced. The filter housings are cleaned carefully, and the filter elements replaced by new ones if this is necessary.

System Flushing.—Flushing of the test equipment pumping system is performed to remove any contamination which might be present. This is always done after the initial installation and also following any major repair in which the principal connections have been broken and remade. When the initial installation has been completed and given an electrical checkout, or when the repairs have been completed, the equipment is turned on and the oil is allowed to circulate for a period of time as required by the equipment handbook.

The equipment is then turned off and the oil is removed from the system. The dirty oil is discarded and the input oil filters are replaced. The reservoir is then filled with the recommended fluid, an example being Univis J–43, a red oil (AN–VVO–336, MIL–O–5606). When the reservoir is filled to the correct level, the system is then ready to supply oil to the missile for testing purposes or for charging the system for flight.

If the missile-borne hydraulic components become contaminated, they must be removed from the missile and reworked in a component repair shop. This type of repair is done only at a major shore repair station and not aboard ship.

Hydraulic Troubleshooting.—Except for the electrohydraulic components, most troubleshooting in hydraulic systems is accomplished by visual means. The trouble of most frequent occurrence is some type of leak resulting from poor connections or from faulty O-rings. Normally, when connections show evidence of leaking fluid, tightening of the connections will be sufficient to stop the loss of fluid. When the leak results from a bad O-ring, it may be necessary to disassemble the unit and replace the ring. If any leak cannot be repaired by these methods, it is necessary to replace the component and return it to a repair activity.

Care of Pneumatic Equipment.—In general, the same periodic inspections and the basic precautions required for hydraulic systems are also valid for the maintenance of pneumatic equipment. The micronic filter elements of the

system must be inspected for cleanliness and replaced at regular intervals; and the filter housing must be kept clean. Pneumatic units which become contaminated cannot be flushed as can hydraulic systems but must be disassembled and cleaned in the manner prescribed by the appropriate maintenance handbook.

Leaks in air or nitrogen systems can usually be found with the aid of a soap solution applied to the suspected connections or joints. The presence of a leak is revealed by the formation of bubbles. Tightening of a leaking connection or the replacement of the associated O-ring is usually sufficient to effect the needed repair.

MISSILE LOGS, RECORDS, AND REPORTS

Missile Logs

Among the more important clerical duties of the personnel of a Guided Missile Division or a Guided Missile Shop are those of keeping a Shop Log and many Missile Logs.

A Shop Log is maintained on a job-order basis. When work is done on a missile, an entry is made in the Shop Log recounting the problem encountered; the nature of the work done; and new components incorporated; the resulting final status of the missile; and the date and time the work was finished. The senior petty officer of the check crew signs the log entry upon completion.

In all the procedures described in this chapter and the chapter preceding, perhaps the consideration of greatest importance are those of safety, both of personnel and of equipment. This subject is reserved for special treatment in the following chapter, which contains authorized precautions and safety rules applicable to the work of the missileman.

QUIZ

1. Operational, technical, and depot are three types of
   a. adjustments
   b. checks
   c. reports
   d. maintenance
2. The primary technical duties of the Guided Missileman include the
   a. adjustment, maintenance, and testing of guided missile radar and auxiliary equipment
   b. maintenance, adjustment, and testing of special test equipment only
   c. assembly and loading of guided missiles
   d. assembly, adjustment, maintenance, and testing of guided missiles systems and components
3. The *Naval Aeronautic Publication Index* is divided into
   a. four parts
   b. three parts
   c. two parts
   d. one part with a supplement
4. The consolidated listing of all publications and forms which pertain to ordnance activities are contained in the
   a. *Naval Aeronautic Publication Index*
   b. *Index of Ordnance Publications*
   c. ESO master index
   d. *BuOrd Manual*
5. In signal tracing, the outputs are checked with test instruments having a
   a. high impedance
   b. high power factor
   c. low impedance
   d. low power factor
6. In troubleshooting, the unit under test is supplied input test signals from
   a. special component test equipment
   b. the Nobatron
   c. the high voltage power supply
   d. the oscilloscope
7. The flux used in soldering electronic and electrical circuits is
   a. soft flux
   b. hard flux
   c. acid flux
   d. rosin flux

8. Good connections in soldering result from
   a. using extra amounts of heat
   b. using special fluxes
   c. clean parts and careful techniques
   d. joints with thick layers of solder
9. Overheating of missile components while soldering is prevented by using
   a. bus-bar
   b. steel pliers
   c. a thermal shunt
   d. an insulation grip
10. The colored dot on one side of the base of a subminiature tube signifies
   a. the tube is a triode
   b. pin one
   c. the plate lead
   d. tube type
11. A resistor with the JAN designation of RC 42 GF 243 J has a resistance of
   a. 24,000 ohms
   b. 243 ohms
   c. 400 ohms
   d. 42 ohms
12. A resistor with a resistance tolerance designator of K has a tolerance of
   a. 1%
   b. 20%
   c. 5%
   d. 10%
13. An axial-lead resistor with bands colored violet, black, yellow, and silver reading from left to right has a resistance of
   a. 7.04 ohms
   b. 704 ohms
   c. 700,000 ohms
   d. 70,000 ohms
14. The capacitance value of a color coded JAN mica capacitor is in
   a. micromicrofarads
   b. microfarads
   c. millifarads
   d. farads
15. The JAN designation of a fixed ceramic-dielectric capacitor is CC–25–SL–100–G. The SL designation indicates
   a. type of dielectric
   b. temperature characteristics

c. capacitance value

d. component type

16. Electrical brushes in rotating power equipment are cleaned with

a. a wire brush

b. MUL-2190 oil

c. a lintless clean cloth

d. Stoddard's solvent

17. A general precaution of importance which applies when working with fluid systems is

a. temperature control of the work area

b. close observation of the pressure

c. proper clothing

d. cleanliness of work area and equipment

18. When flushing a system, the oil is allowed to circulate in the system for

a. about 10 minutes

b. about 30 minutes

c. about one hour

d. period of time specified by the handbook for the equipment

19. Contaminated missile hydraulic components are reworked at a

a. ship's missile shop

b. major shore repair station

c. contractor's facilities

d. manufacturer's depot

20. The Shop Log is maintained by

a. the commanding officer

b. the missile officer

c. senior petty officer of the check crew

d. the log yeoman

CHAPTER 16

SAFETY PRECAUTIONS AND FIRST AID

INTRODUCTION

Most of the duties of the Guided Missileman require constant vigilance and regular observance of safety measures. The safety precautions which apply to the work and duty of the Guided Missileman include those concerning routine missile operations; work with electrical and electronic equipment; work involving the handling of explosive ordnance material; work done in and around aircraft; work in limited spaces, and in proximity to equipment capable of starting fire or generating noxious gases when overheated; the use of high-pressure liquid and pneumatic systems; and work done with hand and small power tools. In addition, the missileman is required to know the authorized methods for treating burns and for giving artificial respiration to persons suffering from electrical shock.

Because of the many specialized devices he uses, and because of the potential hazards in his work, the missileman should consider the formation of safe and intelligent work habits as being equal in importance to the development of his technical knowledge and skills. He should strive to exhibit the attitudes and practices which are characteristic of "safety mindedness." One of his objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions and in avoiding unsafe actions.

This chapter, "Safety Precautions and First Aid," is in no way an exhaustive treatment of safety practices. Each missileman is expected to know and practice those safety precautions for each particular situation as set forth in local directives, in equipment maintenance manuals and in the *United States Navy Safety Precautions*, OP34P1.

BASIC SAFETY PRECEPTS

Under the heading "Basic Precepts," the *United States Navy Safety Precautions* (OpNav 34P1) makes the following statement:

"Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts." This publication then gives the following safety precepts which apply to personnel in all types of activities:

"Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

a. *Reporting unsafe conditions.* Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

b. *Warning others.* Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

c. *Personnel protective equipment.* Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performance of his work or duty.

d. *Report injury or ill health.* All personnel shall report to their supervisor any injury or evidence of impaired health occurring in the course of work or duty.

e. *Emergency conditions.* In the event of an unforeseen hazardous occurrence, each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

BASIC SAFETY PRECAUTIONS FOR MISSILE WORK

Missile Handling

GENERAL SAFETY PRECAUTIONS.—All missile handling must be carried out in accordance with approved local safety regulations in force on shipboard, at depots, or

wherever the work is accomplished. Detailed precautions must be observed, and specific instructions must be followed with each type of guided missile. These are given in the handbook or other classified publications pertaining to the missile.

Work areas must be kept clear of obstructions, loose cables, hose, and any unneeded equipment during missile assembly and testing. Only those persons engaged in the work in progress should be permitted in the work area or in the vicinity of the missile at these times.

All rocket motors and explosive units must be handled in strict accordance with standard Navy practices for ordnance materials.

Only authorized handling equipment should be used with any missile, or with any missile section, component, or related parts, including shipping crates and containers.

Care should be taken to see that all electrical equipment used in missile handling operations is adequately shielded and grounded.

UNCRATING, ASSEMBLY, AND DISASSEMBLY.—Care should be taken to avoid injury, from sharp edges which are often present on nose assemblies, wings, and tail fins. After assembly, all dangerously sharp edges should be covered with guards.

Tools used for uncrating missile components during assembly must be of the type specified in the missile handbook.

Never attempt to force any unit; if it does not fit or function properly, determine the cause and correct it before proceeding.

Precautions With High-Pressure Fluid Systems

GENERAL SAFETY PRACTICES.—When any hydraulic unit is disassembled for inspection or repair, be sure that the workbench is thoroughly cleaned, of dirt and metal filings.

Never use carbon tetrachloride, lacquer thinner, or similar liquids for cleaning hydraulic units. Use only the cleaning solvents or other materials specified in the missile handbook.

Keep the hands and other parts of the body well clear of exhaust streams when working with test equipment employing high pneumatic pressures.

PRECAUTIONS WHEN HANDLING OR CHARGING GAS BOTTLES.—The wing-servo units in many missiles are supplied with primary power by means of an accumulator charged from gas bottles, or cylinders, containing compressed air or nitrogen. The high pressures used in those units make it necessary that extreme caution be exercised by personnel charging the accumulators and gas bottles or handling the containers in which the gases are stowed.

1. When charging gas bottles, be sure that all personnel not required for the work are cleared from the area. Proper protective equipment including goggles must be worn by all persons during charging.

2. Never drop gas cylinders or permit them to strike each other violently.

3. When returning empty cylinders, be sure that all valves are closed, that valve protection caps are in place, and that the proper residual pressure is maintained.

4. Do not tamper with any safety device or valve on the container or the associated equipment.

5. Do not refill any container with gas unless such action has been specifically approved and then only in accordance with explicit instructions. Explosive mixtures may be obtained in cylinders containing traces of combustible gases when these are refilled with compressed air.

6. Do not use regulators, pressure gages, manifolds, and related equipment provided for a particular gas on cylinders containing a different gas.

7. Never discharge a cylinder into any device or equipment wherein the gas will be entrapped and build up pressure unless the cylinder is equipped with a pressure regulator or other device for controlling the pressure.

8. When testing for leaks in a gas container, use soapy water.

9. When it becomes necessary to drain cylinders containing toxic or irritant gases, be sure that there is no possible hazard to personnel or property. For these operations, personnel should be provided with protective clothing, goggles, and breathing masks.

ACCUMULATOR HANDLING AND CHARGING.—Pressure accumulator units in hydraulic systems must be charged with dry air (or nitrogen) and hydraulic fluid in strict accordance with the procedure given in the missile publication. Never charge an accumulator with oxygen.

All hydraulic fluid and air charges must be discharged from accumulator units before the wing-control section is removed. High pressures, capable of causing injury to personnel and damage to equipment, exist at the connection between the wing section and the accumulator unit when the latter is charged with hydraulic fluid.

Safety Precautions for Systems Test

All missile test equipment must be operated by properly qualified personnel only. Before applying test pressures to the missile, be sure that all air and hydraulic connections are well secured. A loose connection is dangerous, since the pressures used are generally capable of causing serious injury and damage.

Check all missile ground wires to see that they are in place before starting a test.

Keep fingers and hands away from wings and fins when the control section of the missile is energized to avoid injury from moving surfaces.

Before hydraulically operated units are put into operation, be sure that all personnel not needed in the process are cleared from the area.

Upon completion of systems tests be sure that the air and hydraulic supplies have been turned off and bled before removing the lines from the missile.

Ordnance Precautions

Missile ordnance materials include rocket motors, igniters, fuses, warheads, and in some cases boosters, or auxiliary

rockets. All of these units are potentially dangerous; and any particular unit must be handled in accordance with the specific procedures authorized for it in the appropriate publication. The following precautions are to be observed in addition to the detailed directions given in the handbooks of particular missiles.

General Precautions.—All safety devices provided in ordnance units must be used exactly as designated. These devices must be kept in order and operative at all times.

Changes, modifications, or additions to ordnance items must be only upon explicit direction by the bureaus concerned.

No explosive assembly is to be used in any way or in any appliance except that which is designated by the proper authority.

Handling, Fuzing, or Inserting Igniters in Ordnance Materials.—Electric igniters, VT fuzes, detonators, and electrically fired rocket motors must be carefully protected from radio-frequency omissions. None of these units should be exposed within five feet of any operating electronic transmitting equipment, including antennas and antenna leads. When the transmitting apparatus is a part of authorized test equipment or is a part of the weapons system, special instructions concerning its operation must be followed. No danger exists, however, from radio-frequency pontentials with detonators of any type while they are completely enclosed in metal containers.

Warheads and fuzes must be protected from abnormally high temperatures. If exposed, they must be handled in accordance with current instructions of the bureau concerned.

Normally, warheads are issued unfuzed. Fuzes shall not be inserted until just prior to flight time. Fuzing shall not be accomplished near a magazine, but may be accomplished in handling rooms or spaces specially designated by competent authority. When fuzing takes place, missiles should be isolated from other ammunition as far as is practicable.

Be sure that the missile airframe is well grounded electrically at all times. Before connecting igniters in rocket

motors, check the firing leads for stray or induced voltages and for static charge.

Before handling any piece of ordnance material, inspect the safety device to be sure that it is in the SAFE position. If not, the unit must be made safe by experienced personnel before further work is carried out.

Before connection in rocket motors, the igniter should be inspected to see that the case and safety switch are free from damage. If any is found, the entire assembly should be rejected.

Safety pins in fuzes, or any other device requiring removal or adjustment before flight, must be removed or adjusted only after the missile has been loaded on the launcher.

Missiles not expended on live runs must be made safe at the first opportunity in accordance with current instructions for the various ordnance assemblies.

PRECAUTIONS WITH ROCKET MOTORS.—No motor assembly that has been dropped should be fired. Care should be taken to avoid dropping or otherwise shocking the motor assembly, since the solid fuel is fragile and becomes dangerously explosive when broken.

Disposal of rejected motor assemblies and subassemblies must be made in exact accordance with local regulations governing the particular type of unit.

Never use power tools for any work on the motor nor apply heat to it or to any associated component.

Some rocketmotors can be ignited by static charges carried by personnel or built up on ungrounded equipment. Be sure that the motor case is grounded during all handling operations.

In case of rocket motor misfire, personnel must not approach the rocket for at least 10 minutes, nor until the firing circuits are known to be open.

If, during handling, it is learned that any motor or booster is in the armed condition, the unit must be disarmed before proceeding with further activity.

Storage and Stowage Precautions.—Explosives and propellant devices must be stowed only in magazines which are specifically designated and approved and in which the temperature never exceeds safe values.

Magazines in which ordnance materials are stored must be kept scrupulously clean and dry at all times. Nothing should be stored in any magazine except the designated materials and authorized magazine equipment.

Particular care must be taken to insure that no oily rags, waste, or other foreign materials capable of spontaneous ignition are present in magazines.

Naked lights, matches, or flame-producing apparatus must never be taken into ordnance magazines or into other spaces containing ordnance materials.

All explosives should be moved to safe storage before performing any work which may cause either abnormally high temperature or an intense local heat in a magazine or any compartment used as a magazine until normal conditions have been restored.

All ordnance materials are to be securely fastened in approved types of racks during storage. Removal from the racks should be accomplished by use of authorized handling equipment only; and before using this equipment, it should be checked to be sure that it is in proper working order.

Always check any component containing a safety and arming device (such as a rocket motor, a fuze, igniter, or booster) to be sure that it is in the SAFE condition before placing it in storage.

Ground wires must be attached to propulsion units in storage, in checkout, and while being transported from one area to another.

Miscellaneous Ordnance Precautions.—Flares (often used in missiles with command guidance as well as other types) and similar pyrotechnic materials must be kept, prior to use, in special pyrotechnic storage spaces or in pyrotechnic lockers on upper decks. When handling ordnance materials of this kind, care should be taken that the minimum amount possible is exposed at any given time.

All personnel working with chemical ammunition should be properly qualified and trained in the fundamentals of handling toxic chemicals, and should be familiar with the use of authorized handling equipment, including protective clothing and gas masks.

Launcher firing circuits should be tested only after determining that rockets are not installed. All personnel should exercise care to keep clear of the possible exhaust paths of rockets at all times.

Precautions When Working Near Aircraft

In addition to all local orders and directives, the following precautions should be observed:

Remain constantly on the alert to avoid injury to or damage to person or property, caused by slipstream, jet blast, or rocket blast.

Stay clear of jet intakes and propellers.

Do not smoke or bring any type of open flame within 50 feet of any parked aircraft. Remember that vapor from aviation fuel can be ignited in a number of ways—by lighted cigarettes, by static discharges, and by sparks from tools or from electrical and electronic equipment.

See that combustible materials such as rags and clean waste are stowed in metal containers. Used waste and rags should never be discarded near aircraft but should always be put in plainly marked METAL receptacles.

SAFETY PRECAUTIONS FOR MISSILE ELECTRONIC WORK

Most of the safety rules for electrical work also apply to the operation, repair, and maintenance of missile electronic equipment. In addition, special precautions must be taken against the high potentials normally present in electronic devices; against dangerous effects of radiated energy; and against possible injury when handling electronic component parts.

The standard safety measures to be taken by personnel engaged in electronic work include those pertaining to per-

sonal protection, to work done on electronic equipment, and to safety from fire.

Personal Protection

CLOTHING.—The following general rules apply to clothing worn during electrical work:

1. Do not work on electronic apparatus with wet hands or while wearing wet clothing or any clothing which is loose and flapping.

2. When working within four feet of electronic equipment do not wear clothing with exposed zippers, metal buttons, or any type of metal fastener. No flammable articles, such as celluloid cap visors, should be worn.

3. Personnel should remove rings, wristwatches, bracelets, and similar metal articles when working on or within four feet of electronic equipment having exposed current-carrying parts.

4. When working on or near electronic apparatus personnel shall wear high-cut shoes with sewed soles or safety shoes with nonconducting soles, if these are available. The use of thin-soled shoes and those with metal plates or hobnails is prohibited.

PROTECTIVE EQUIPMENT.—Danger signs and suitable guards should be provided to warn all personnel wherever live parts of electric circuits and equipment are exposed when the voltages involved are 50 volts or greater.

Insulating floor covering should be used in work areas where electronic equipment is serviced, particularly where the deck or walls are of metallic construction.

Interlocks, overload relays, fuses, and other protective devices should never be altered or disconnected except for replacement, nor should any safeguard circuit be modified without specific authorization.

Metal enclosures for electrical and electronic equipment must be kept effectively grounded.

HIGH-VOLTAGE PRECAUTIONS.—Adjustment, repair, and maintenance of missile radars, radio units, and test equipment must be done only by duly authorized personnel.

Adjustment of transmitters and other high-voltage equipment should not be attempted while the motor-generator is running or while the rectifiers are energized, unless the adjustments can be made by the use of exterior controls provided for the purpose.

Except in emergencies or when it is considered essential by the proper authority, repairs should not be made on energized electronic equipment. If such work is necessary, it should be undertaken only by experienced personnel; and all safety precautions pertaining to work on energized circuits should be observed.

PRECAUTIONS AGAINST ELECTRIC SHOCK.—Adherence to the rules concerning clothing and protective equipment is essential in areas where electrical work is done and serves as an aid in preventing shock. Other safety precautions to be taken are as follows:

1. Never work alone near high-voltage equipment.

2. Exercise caution when using tools with metal parts, metal tapes, cloth tapes with embedded metal threads, and cleaning equipment containing metal parts. None of these should be used in any area within four feet of electronic equipment or wiring having exposed current-carrying parts.

3. Any person working on or around electronic circuits should be very careful to keep his attention from wandering and becoming diverted from the work.

4. Exercise as much care to avoid contact with low voltages as with high voltages. Never take a shock intentionally from any source; this is a dangerous practice and is strictly forbidden. If a particular circuit operates normally at 600 volts or less, and it is necessary to determine whether it is energized, use a voltmeter, voltage tester, or other suitable indicating instrument.

5. Before the terminals of apparently deenergized equipments are touched, short them together and to ground, using a suitably insulated shorting device.

RADIO-FREQUENCY CIRCUITS.—When nearby transmitting equipment is in operation, workers should be on the alert to avoid shock and burns resulting from contact with antennas, antenna leads, and other exposed parts.

Special precautions concerning ordnance material should be observed before "firing" transmitters.

Radar and radio transmitters should never be operated within 75 feet of where fueling operations are in progress in aircraft. Also, no transmitter should be energized within an aircraft following fueling until the hull has been thoroughly ventilated and cleared of fumes, or at any time when gasoline vapors appear to be present.

Transmitting antennas of high-frequency equipment must not be energized whenever they are less than 50 feet from the following hazards:

1. Guns with electric firing circuits, when not installed in shielded mounts or turrets, either during the process of loading or in the loaded condition.

2. Ammunition fitted with electric primers, when not in a mount, turret, or an ammunition container.

3. Unshielded flare circuits in aircraft when the flares are installed.

4. Oil-fueling operations during the intervals when the metallic hose connections are either made or broken.

CRYSTAL DIODES.—Static electric charges carried by the worker can burn out crystal diodes, which are often used in missile radar receivers. When installing a crystal, the cartridge should be held with the fingers touching one end only. The hand holding the unit should then be grounded against the missile airframe before the end of the crystal is brought into contact with the holder.

CAPACITORS.—Before a worker touches a capacitor, either connected in a deenergized circuit or disconnected entirely, he should always short-circuit the terminals to be sure that the capacitor is completely discharged. A suitably insulated lead or a grounding bar should be used for this purpose.

Grounded shorting prods should be attached permanently to workbenches where electronic units are regularly serviced or overhauled.

Care should be taken when using tools made of magnetic materials near radar magnetrons, since the tool can be pulled by the magnet into contact with dangerous, high-voltage circuits.

FUSES.—Fuses should be removed and replaced only after the circuit has been completely deenergized. When a fuse "blows," it should be replaced only with a fuse of the same current rating. When possible, the circuit should be checked carefully before making the replacement since the burned-out fuse usually results from a circuit fault.

SWITCHES.—As a general rule, electronic equipment must be deenergized before work such as overhaul or repair is performed. The power source must be disconnected from the equipment by opening the main or branch supply switches, circuit breakers, or cutouts so as to eliminate completely any possibility of current flowing to the device.

CATHODE-RAY TUBES.—The principal hazard when handling large cathode-ray tubes is the possibility of implosion, or the collapse of the glass envelope under atmospheric pressure. The tubes are not dangerous if properly handled: but if they are struck, dropped, scratched, or treated carelessly, they can well become an instrument of severe injury or even death. During installation or removal of these tubes, the following precautions should be taken:

1. Wear goggles to protect the eyes; fracture of the envelope combined with vacuum within the tube can result in flying glass particles.

2. Wear suitable gloves to protect the hands.

3. Be sure that no part of the body is exposed directly to possible glass splinters. Do not handle glass fragments since the coating on some tubes is poisonous and can enter the blood stream through cuts in the skin.

4. When the tube is needed, remove it from the packing box with caution, taking care not to strike or scratch the

envelope or to expose it to possible damage. Insert the tube into the equipment socket, using moderate pressure and without jiggling it. Use the same procedure when removing the tube from the equipment.

5. If the tube must be set down, place the tube face down on a clean, soft padding. Avoid standing directly in front of the tube face since implosion often causes fragments to be propelled forward with great force.

SELENIUM RECTIFIERS.—When selenium rectifiers burn out, fumes of selenium dioxide are liberated, causing an overpowering stench. The fumes are poisonous and should not be breathed. When a rectifier burns out, deenergize the equipment immediately, ventilate the compartment, and allow the damaged unit to cool before attempting any repairs. If possible, remove the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is still hot, since a skin burn might result through which some of the selenium compound could be absorbed.

BATTERY PRECAUTIONS.—When working with batteries, precautions must be taken against shock and accidental shorting of the terminals, and against the possibility of injury resulting from contact with the electrolyte. The standard safety measures which apply in most cases include the following:

1. TOOLS. Use tools with insulated handles when removing or replacing batteries.

2. INSTALLATION. When replacing a battery which has one terminal grounded, remove the grounded terminal first and do not reconnect it until the new battery is in place and the other connections have been made.

3. ACID ELECTROLYTE. When preparing or handling solutions of sulfuric acid for use in lead-acid cells, observe the following precautions:

a. Never pour water into acid. The acid must be poured slowly into the water.

b. Guard the eyes and skin from splashing acid.

c. Do not store sulfuric acid in places where freezing temperatures are possible.

d. Keep the electrolyte in the cells at a level just above the separators.

4. ALKALINE ELECTROLYTE. In missile systems, battery cells containing corrosive alkaline solutions are often used. Examples are silver-zinc and nickel-cadmium batteries, in both of which the electrolyte is a solution of potassium hydroxide (KOH). This solution is active chemically; and extreme care should be taken to avoid spilling or splashing it on the skin, on clothing, or on surrounding equipment. If this occurs, the affected areas should be flushed immediately with large quantities of water. Afterwards, the chemical can be neutralized with a weak (10%) solution of acetic acid, if this is available.

Preparation of electrolyte should be done only by experienced personnel.

All mixing should be done in heat-resistant, plastic jars; and every precaution should be taken to prevent high temperatures from developing in the solution.

Constant stirring is necessary, using a monel metal paddle.

The solution should be stored in hermetically sealed, plastic containers; and these should not be opened until the electrolyte is needed for filling the cells.

CLEANING.—The following general rules apply when cleaning electronic and electrical equipment:

1. Alcohol, benzene, gasoline, and similar flammable liquids should never be used as cleaning agents, either on energized or deenergized apparatus. The use of alcohol is especially undesirable since it not only constitutes a fire hazard but it also results in damage to many kinds of insulation.

2 Never use carbon tetrachloride as a cleaning solvent. Unlike alcohol, it is not a possible source of fire; it is hazardous because of the dangerous effects of breathing its vapors. Careless use of carbon tetrachloride may result in headache, dizziness, and nausea. If the fumes are breathed in poorly ventilated compartments, the result may be loss of consciousness or even death.

3. The recommended solvent for cleaning electronic equipment is Dry Cleaning Solvent Spc. #O–T–00620. Additional instructions for the use of this solvent and other cleaning agents are contained in pertinent Bureau of Ships Instructions.

4. When "blowing out" equipment with compressed air, use rubber hose or other suitable insulated hose as air lines. The pressure should not exceed 50 pounds and the air should be free from moisture. Never turn compressed air on yourself or on others since it can cause serious injury.

Electrical Fires

General cleanliness of the work area and of electronic apparatus is essential for the prevention of electrical fires. Oil, grease, and carbon dust can be ignited by electrical arcing; hence, electronic equipment should be kept absolutely clean and free from all such deposits.

Volatile liquids, such as gasoline, insulating varnish, lacquer, turpentine, and kerosene, are dangerous when exposed near operating electrical or electronic units. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

In case of fire occurring in or around electronic apparatus, the following steps should be taken:

1. Deenergize the equipment.
2. Call the Fire Department, if ashore or the OOD and others designated by proper authority if aboard ship.
3. Control the fire as far as possible with the correct type of fire fighting equipment until the Fire Department or Damage Control Party arrives.

For combating electrical fires, use only dry-chemical carbon dioxide (CO_2) extinguishers, or other types authorized for class C fires (those involving electrical devices). Carbon tetrachloride should never be used for fire fighting since it changes to phosgene (a poisonous gas) upon contact with

hot metal; and even in open air, this gas creates a hazardous condition. The application of water to electrical fires is dangerous; and foam-type extinguishers should not be used since the foam is electrically conductive.

In case of cable fires in which the inner layers of insulation are burning, the only positive method of preventing the fire from running the length of the cable is to cut it and separate the two ends.

SAFETY WHEN USING TOOLS

As a general precaution, be sure that all tools used conform to Navy standards as to quality and type; and use each tool only for the purpose for which it is intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools are to be returned to the toolkeeper.

HAND TOOLS.—Care must be taken when selecting pliers, side cutters, or diagonal cutters. Pliers or cutters should never be used on nuts or pipefittings. Always hold the pliers or cutters so that the fingers are not wrapped around the handle in such a way that they can be pinched or jammed if the tool slips. When cutting short pieces, take care that parts of the work do not fly and cause injury. Never put extensions on tool handles to increase leverage.

When selecting a screwdriver for electrical work, be sure that it has a nonconducting handle. The screwdriver selected should be of the proper size to fit the screw and should never be used as a substitute for a punch or a chisel. The points of screwdrivers can be kept in proper shape with a file or a grinding wheel.

Use wrenches only if they are right for the job and only if they are in good condition. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned.

PORTABLE POWER TOOLS.—All portable power tools should be inspected before use to see that they are clean, well oiled, and in the proper state of repair. The switches should op-

erate normally, and the cords should be clean and free of defects. The case of any electrically driven power tool should be well grounded; and sparking electric tools should never be used in places where flammable gases or liquids or exposed explosives are present.

DRILLS must be straight, undamaged, and properly sharpened. Tighten the drill securely in the chuck using the key provided; never secure it with pliers or with a wrench. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before drilling is started.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor should they be allowed to come in contact with oil, grease, hot surfaces, or chemicals. When cords are damaged, they should be replaced instead of being patched with tape.

FIRST AID

Treatment for Electric Shock

Electric shock is a jarring, shaking sensation resulting from contact with high-voltage circuits or from the effects of lightning. The victim usually feels that he has received a sudden blow; and if the voltage is sufficiently high, the victim drops down unconscious. Severe burns may appear on the skin at the place of contact; and muscular spasm can occur, causing him to clasp the apparatus or wire which caused the shock and to become unable to turn it loose.

The following procedure is recommended for rescue and care of shock victims:

1. Remove him from electrical contact at once, but DO NOT ENDANGER YOURSELF. This can be done (1) by throwing the switch if it is nearby; (2) by cutting the cable or wires to the apparatus, using an ax with a wooden handle while taking care to protect your eyes from the flash when the wires are severed; (3) by use of a dry stick, rope, leather belt, coat, blanket, or any other nonconductor of electricity.

(2) Determine whether the victim is breathing. If he is, keep him lying down in a comfortable position. Loosen the clothing about his neck, chest, and abdomen so that he can breathe freely. Protect him from exposure to cold, and watch him carefully.

3. Keep him from moving about. In this condition, the heart is very weak, and any sudden muscular effort or activity on the part of the patient may result in heart failure.

4. Do not give stimulants or opiates. Send for a medical officer at once and do not leave the patient until he has adequate medical care.

5. If the victim is not breathing, it will be necessary to apply artificial respiration without delay, even though he may appear to be lifeless.

Resuscitation From the Effects of Electric Shock

Artificial respiration is the process of promoting breathing by mechanical means. It is used to resuscitate persons whose breathing has stopped, not only as a result of electric shock, but also from causes such as drowning, asphyxiation, strangling, or the presence of a foreign body in the throat.

When a shock victim is to be revived, begin artificial respiration as soon as possible. If there is any serious bleeding, stop it first, but don't waste time on anything else. Seconds count; and the longer you wait to begin, the less are the chances of saving the victim.

The approved method of artificial respiration is the back-pressure, arm-lift technique illustrated in figure 16–1.

Place the victim in the face-down, or prone, position. Bend both his elbows and place one of his hands on the other. Turn his face so that it is resting on his hands. Quickly sweep your fingers through his mouth to clear it out and be sure that the throat is open. With the same movement, bring the tongue forward so that it cannot stop the air passage.

Kneel at the victim's head, facing him. Kneel on either knee, or on both—whichever is most comfortable. Next, place your hands on his midback, just below the shoulder

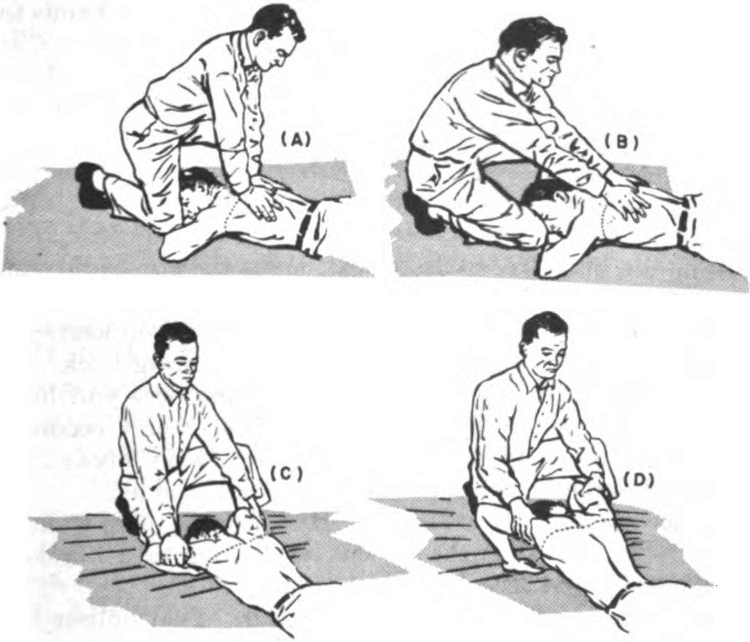


Figure 16–1.—The back-pressure, arm-lift method of artificial respiration.

blades, so that the fingers are spread downward and outward and the thumb tips almost touching. This phase is shown in (A) of figure 14–1.

Rock forward until your arms are approximately vertical; and allow the weight of the upper part of your body to exert a slow, steady pressure on your hands until form resistance is met. This action, shown in (B) of figure 14–1, causes the chest to be compressed so that air is forced out of the lungs. Keep your elbows straight and your arms almost vertical so that the pressure is exerted downward.

Be very careful to avoid exerting sudden or excess pressure, and be sure that your hands are not too high up on the victim's back or on his shoulder blades. Release the pressure quickly. "Peel" your hands from his ribs without any

extra push. Then rock backward and allow your hands to come to rest on the victim's arms just above his elbows, as shown in (C) of figure 14–1. As you rock backward, draw his arms upward and toward you. Keep your arms nearly straight, as shown in (D) of the same figure.

Lift the victim's arms until you feel resistance and tension at the shoulders. The arm lift pulls on the chest muscles, arches the back, and relieves the weight on the chest, thus pulling air into the lungs. Next, lower the arms, and you have completed one full cycle.

The complete cycle can be chanted to help you keep the rhythm—"Place . . . Swing forward . . . Swing back . . . Lift." Keep this rhythm without stopping once you have begun. The four steps should take about 5 or 6 seconds, allowing 10 or 12 cycles per minute. Don't break the rhythm no matter what else is being done, such as:

1. Keeping the victim warm. If someone is there to help you, have him wrap the patient in clothing or a blanket. This can be done between cycles.

2. Loosening his belt or tight clothing. Your helper can do this too.

3. Moving the victim. This is to be done only if you must, because of foul weather, fire, or other hazard. After he is breathing on his own, he may be moved, but only in a lying-down position.

When resuscitating a shock victim by artificial respiration, don't give up too soon. Sometimes it takes several hours. Be certain that all chance of saving him is gone before you think of stopping.

Keep watching the patient even after he starts to breathe again. If he stops, you must start artificial respiration again immediately. Keep him lying down and warm, even after he revives.

Treatment of Electrical and Thermal Burns

In administering first aid for burns, the objectives are to relieve the pain, to make the patient as comfortable as pos-

sible, to prevent infection, and to guard against his going into a state of shock which sometimes accompanies burns of a serious nature.

The greatest pain from a burn is caused by the movement of air over the damaged area. As a first step, cover the burn with some substance which will exclude the air. When the skin is merely reddened and is not broken, the burned area may be covered with a coating of vaseline. Never put iodine on a burn; and do not apply an antiseptic or a powder. Do not put cotton directly on the burn since it will stick and cause further injury.

If the skin is blistered or if the flesh is cooked and charred, secure the services of a medical officer or a corpsman as soon as possible. If medical aid cannot be obtained in a short time, proceed to dress the burned areas as follows:

1. Remove charred materials from the injured surfaces, taking care not to break any blisters which may be present. If clothing is stuck to any part of the surface, do not pull it loose, but cut around the clothing and let it stay attached.
2. Apply thin pieces of sterile vaseline gauze directly over the burned areas.
3. Apply cotton wadding or gauze fluffs over the top of the gauze to give the dressing bulk.
4. Apply elastic bandages to make a snug pressure dressing.
5. Have the patient transferred to a hospital as soon as possible.

QUIZ

1. Authorized safety precautions require that electric igniters, detonators, rocket motors, and fuzes shall not be exposed within what minimum distance in feet from any operating transmitter?
   a. 2
   b. 3
   c. 5
   d. 10

2. The principal hazard when handling large cathode-ray tubes is the possibility of
   a. explosion
   b. implosion
   c. alpha-ray exposure
   d. delta-ray exposure

3. Navy safety precautions require that during refueling of aircraft, radar equipment must not be operated within a minimum of ---- feet of the plane.
   a. 25
   b. 50
   c. 75
   d. 100

4. Danger signs should be provided to warn all personnel where live parts of electrical circuits are exposed and where the voltages involved are at least ------ volts.
   a. 1000
   b. 500
   c. 50
   d. 25

5. A standard safety practice when replacing blown fuses is to
   a. replace with fuse of amperage rating within 20 percent of blown fuse
   b. completely deenergize circuit before replacing
   c. have an assistant stand by gear with fire bottle
   d. replace with larger fuse until cause of overload has been determined

6. Rocket motors which have been dropped shall be
   a. fired as soon as possible
   b. discarded in accordance with local regulations
   c. repaired by authorized personnel
   d. checked on rocket motor stand

7. The first thing to do after removing an electrical shock victim from electrical contact is to
   a. check his or her pulse
   b. check for breathing
   c. cover with blanket
   d. make victim comfortable

8. When mixing sulfuric acid and water
   a. pour water into acid
   b. pour acid and water into container at same time
   c. pour acid into water
   d. insure that both are below 60° F

9. If an alkaline battery electrolyte is spilled on the skin, it should be flushed off immediately with large quantities of
   a. water
   b. baking soda
   c. hot concentrated solution of H_2SO_4
   d. a weak solution of acetic acid

10. When selenium rectifiers have burned out,
   a. remove immediately from equipment using special gloves
   b. immediately disconnect from electrical circuit
   c. immediately douse with CO_2
   d. ventilate the compartment

11. Carbon tetrachloride should never be used to clean electronic equipment for which of the following reasons?
   a. It creates a fire hazard.
   b. It damages most kinds of insulation.
   c. It is corrosive and can injure personnel and damage equipment.
   d. It is hazardous to personnel because of the dangerous effects of breathing its fumes.

12. The type of tools for uncrating and assembling missile components will be specified in the
   a. *Missile handbook of service instructions*
   b. *Missile log*
   c. *Missile test equipment handbook*
   d. *Hand tools manual*

13. Before hydraulically operated units are put into operation
   a. hydraulic fluid temperature should be checked
   b. all personnel not needed in the process should be cleared from the area
   c. hydraulic fluid level should be checked
   d. all O-rings should be checked

14. All missile handling must be carried out in accordance with
    a. the *BuOrd Manual*
    b. the *BuShips Manual*
    c. the *BuAer Manual*
    d. approved local safety regulations

15. Explosives and propellant devices must be stowed
    a. in the open
    b. next to missile repair shop
    c. in temperature controlled spaces
    d. completely assembled with other components of missile

16. According to *Navy Safety Regulations*, transmitting antennas in high frequency equipment must not be energized when they are less than a minimum of ------ feet from ammunition fitted with electric primers not in a mount, turret, or an ammunition container
    a. 25
    b. 50
    c. 75
    d. 100

17. ---------- is/are used on an electrical fire.
    a. Foam type extinguishers
    b. CO_2 extinguishers
    c. Soda acid extinguishers
    d. Fresh water hose

18. Normally, fuses are inserted in warheads
    a. at the factory
    b. when missile is assembled
    c. just prior to flight time
    d. any time

19. When administering first aid for burns, any clothing stuck to the burned area should be
    a. removed by the use of distilled water
    b. removed by the use of peroxide
    c. removed by the use of baby oil
    d. left on the burn

20. When testing for leaks in a gas container, use
    a. soapy water
    b. clear water
    c. alcohol
    d. your sense of smell

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

THE GUIDED MISSILEMAN

1. Professional.
2. *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised).
3. NEC's (Navy Enlisted Classifications).
4. d.
5. a.
6. (1) results of preflight checks
   (2) operating times of component parts
   (3) equipment failures
   (4) modifications made to the missile
7. b.
8. b.

CHAPTER 2

INTRODUCTION TO GUIDED MISSILES

1. (1) propulsion system
   (2) guidance and control system
   (3) warhead
   (4) fuze
   (5) aerodynamic configuration and surfaces (air frame)
2. d.
3. b.
4. a.
5. b.
6. a.
7. c.
8. c.
9. a. AAM, b. SSM ; c. SAM
10. (1) basic designation
    (2) service letter
    (3) model number with an associated letter designation
11. X.
12. XSSM-N-2.
13. a.
14. RSAM-A-5c.

CHAPTER 3

FACTORS AFFECTING MISSILE FLIGHT

1. a.
2. c.
3. b.
4. d.
5. a.
6. b.
7. (1) vertical
   (2) longitudinal
   (3) lateral
8. (1) thrust
   (2) drag
   (3) weight
   (4) lift
9. c.
10. d.
11. b.
12. b.
13. c.
14. b.
15. d.
16. Ratio of span to average chord length.
17. b.
18. a.
19. b.
20. d.
21. a.

CHAPTER 4

GUIDED MISSILE COMPONENTS

1. c.
2. a.
3. (1) canard
   (2) wing control
   (3) tail control
4. a.
5. d.
6. d.
7. Umbilical plugs.
8. b.
9. a.
10. (1) impact or contact
    (2) ground or command
    (3) proximity
11. d.
12. b.
13. (1) rigidity in space
    (2) precession
14. d.
15. c.
16. Anti-hunt device.
17. b.
18. computing
19. c.
20. a.

CHAPTER 5

PROPULSION PLANTS AND LAUNCHERS

1. b.
2. a.
3. d.
4. a.
5. b.
6. a.
7. d.
8. Pump feed.
9. b.
10. b.
11. c.
12. d.
13. b.
14. a.
15. c.
16. a.
17. b.
18. (1) fixed
    (2) trainable
19. d.
20. b.

CHAPTER 6

AUXILIARY POWER SUPPLIES

1. d.
2. a.
3. b.
4. a.
5. (1) operating pressure
   (2) speed
   (3) arm length and shape
   (4) nozzle size
6. a.
7. d.
8. (1) air flask or accumulator
   (2) pressure regulator
   (3) air motor
   (4) hydraulic motor
   (5) alternator
9. c.
10. a.
11. b.
12. a.
13. c.
14. (1) shorter preparation time
    (2) longer storage life
    (3) smaller size and weight
    (4) more rugged mechanically
15. b.
16. b.
17. b.
18. c.

CHAPTER 7

GUIDANCE SYSTEMS FOR SURFACE LAUNCHED MISSILES

1. (1) tracking
   (2) computing
   (3) directing
   (4) steering
2. b.
3. (1) launching or initial
   (2) midcourse
   (3) terminal
4. a.
5. c.
6. d.
7. a.
8. c.
9. (1) range
   (2) angle
10. a.
11. b.
12. c.
13. b.
14. c.
15. a.
16. Accuracy increased.

CHAPTER 8

BEAM RIDER GUIDANCE SYSTEM

1. c.
2. a.
3. b.
4. Autopilot system.
5. Servo system.
6. c.
7. (1) free gyros
   (2) rate gyros
   (3) accelerometers
8. a.
9. (1) pitch
   (2) yaw
   (3) roll error
10. d.
11. (1) fly down
    (2) fly left
    (3) fly up
    (4) fly right
12. (1) pitch and yaw
    (2) roll
13. b.
14. a.
15. b.
16. a.
17. d.
18. a.
19. c.
20. a.

CHAPTER 9

HOMING SYSTEM OF MISSILE GUIDANCE

1. c.
2. b.
3. Pursuit homing.
4. Collision course.
5. a.
6. b.
7. c.
8. c.
9. d.
10. b.
11. c.
12. d.
13. b.
14. a.
15. c.

CHAPTER 10

COMMAND, INERTIAL, AND PRESET MISSILE GUIDANCE SYSTEMS

1. c.
2. a.
3. (1) information
   (2) command
4. d.
5. a.
6. d.
7. b.
8. a.
9. c.
10. c.
11. a.
12. b.
13. d.
14. b.
15. a.

CHAPTER 11

INTRODUCTION TO MISSILE CONTROL SYSTEMS

1. c.
2. a.
3. (1) pneumatic
   (2) hydraulic
   (3) electrical
4. d.
5. c.
6. (1) input
   (2) error detecting device
   (3) controller
   (4) output
   (5) feed back
7. c.
8. b.
9. c.
10. d.
11. c.
12. c.
13. a.
14. b.
15. c.

CHAPTER 12

CONTROL SYSTEMS

1. c.
2. b.
3. a.
4. d.
5. b.
6. a.
7. c.
8. d.
9. (1) chevron
   (2) cup
   (3) C- and O-ring
   (4) metallic
10. a.
11. b.
12. b.
13. b.
14. c.
15. b.
16. c.
17. d.
18. d.
19. a
20. b.

CHAPTER 13

INTRODUCTION TO TELEMETERING

1. a.
2. b.
3. c.
4. d.
5. b.
6. b.
7. d.
8. a.
9. b.
10. a.
11. a.
12. a.
13. b.
14. d.
15. a.
16. a.
17. a.
18. a.
19. b.
20. a.

CHAPTER 14

MISSILE HANDLING AND TESTING

1. d.
2. d.
3. a.
4. b.
5. b.
6. a.
7. c.
8. d.
9. a.
10. d.
11. a.
12. d.
13. c.
14. a.
15. b.
16. a.
17. b.
18. c.
19. b.
20. d.

CHAPTER 15

MAINTENANCE AND REPAIR PROCEDURES

1. d.
2. d.
3. b.
4. b.
5. a.
6. a.
7. d.
8. c.
9. c
10. b.
11. a.
12. d.
13. c.
14. a.
15. b.
16. c
17. d.
18. d.
19. b.
20. c

CHAPTER 16

SAFETY PRECAUTIONS AND FIRST AID

1. c.
2. b.
3. c.
4. c.
5. b.
6. b.
7. b.
8. c.
9. a.
10. d.
11. d.
12. a.
13. b.
14. d.
15. c
16. b.
17. b.
18. c.
19. d.
20. a.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

GUIDED MISSILEMEN (GS)

QUALS CURRENT THROUGH CHANGE 10

General Service Rating

SCOPE

Guided missilemen assemble, test, aline, adjust, replace, and repair internal components of surface-launched missiles, excluding jet engine propulsion systems and ordnance items and hydraulic/pneumatic systems not associated with missile internal guidance and control; operate, test, adjust, aline, calibrate, and repair missile test equipment; supervise and train personnel in handling, stowage, test, and repair of guided missile sections and components and associated test equipment; handle and stow missile sections and components; maintain logs and equipment histories.

Emergency Service Rating

Same as General Service Rating.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see *Manual of Navy Enlisted Classification*, NavPers 15105 (Revised), codes GS–1300 through GS–1399.

Qualifications for Advancement in Rating	Applicable Rates GS
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Handle, stow, and secure missile sections and components, excluding ordnance and propulsion equipment on own ship or station; replace desiccant and recharge containers with low pressure air, if required for equipment	3
2. Assemble and disassemble missile component containers on own ship or station; pressurize containers, using low-pressure air supply	3
3. Install and remove missile components from containers; install desiccant and packing materials; secure and release missile components in containers	3
4. Prepare missile sections and components for assembly; visually inspect connections, fittings, and mating surfaces for proper condition for assembly; clean and prepare mating surfaces; remove protective caps from all lines	3
5. Assemble and disassemble missile sections, as member of team, on own ship or station; aline and secure sections; connect and disconnect fittings	3
6. Prepare missile and associated test equipment for missile system test by making proper connections, setting missile and test equipment switches, installing required measuring devices, and setting missile and components in proper location	3
7. Operate missile test equipment under direct supervision; take and verify dial readings; vary signals, and switch positions	3
8. Secure missile and associated missile test equipment after missile system test; set all switches, knobs, and valves for shutting down test; bleed pressurized lines; disconnect all electrical, hydraulic, or pneumatic lines; remove measuring devices mounted on missile for test; disconnect and/or cap all fittings	3
9. Operate voltmeter, vacuum tube voltmeter, ammeter, ohmmeter, multimeter, megger, tube tester, and battery tester	3
10. Draw and interpret schematic diagrams of electrical circuits; read and interpret electrical wiring diagrams found in equipment instruction books	3

Qualifications for Advancement in Rating	Applicable Rates GS
101 OPERATIONAL—Continued	
11. Identify electronic component symbols	3
12. Demonstrate knowledge of electrical, ordnance (solid propellent rocket motors, high explosive warheads, fuzing, igniters), fueling, high-pressure air, hydraulic, jet engine, and mechanical safety precautions	3
13. Extinguish class A, B, and C fires, using approved methods (simulated conditions)	3
14. Rescue person in contact with energized electrical circuit; resuscitate person unconscious from electrical shock and burns (simulated conditions)	3
15. Demonstrate soldering technique and utilization of common hand tools used in missile assembly and replacement of parts	3
16. Locate and identify component parts by reference to associated circuit diagrams and mechanical drawings	3
17. Draw and interpret schematic diagrams of electronic circuits; read and interpret electronic wiring and circuit diagrams found in equipment instruction books	2
18. Operate following standard test equipment used in servicing electronic equipment:	
a. Oscilloscope	2
b. Spectrum analyzer	2
c. Signal generator	2
d. Pulse generator	2
e. Frequency meter	2
f. Impedance bridge	2
g. Resistance bridge	2
h. RF wattmeter	2
i. FM signal generator	2
19. Charge missile internal guidance and control pressurized systems; prepare missile for charging by removing access plates and making required hose connections; charge missile system following check list instructions; use hand tools, charging unit or air supply system	2
20. Fuel propulsion systems if required	2

Qualifications for Advancement in Rating	Applicable Rates GS
102 MAINTENANCE AND/OR REPAIR	
1. Perform tests on batteries for missile or missile test equipment. Replace weak sectionalized cells or complete batteries	3
2. Clean commutators and commutator heads; replace brushes on missile and missile test equipment, rotating electrical machinery such as dynamotor, motor, generator; replace dynamotors, generators, and motors	3
3. Replace fuses, wiring, switches, plugs, jacks, and relays on electrical equipment; make connections	3
4. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits; visually inspect for loose, damaged, broken, or burned components	3
5. Replace identified or isolated vacuum tubes and circuit components, electronic packages, relays, potentiometers, multi-element plugs and jacks; clean contacts, terminal pins, and plugs; make solder connections	3
6. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electronic circuits; adjust potentiometers and controls; substitute components	2
7. Effect changes to electronic circuits in accordance with wiring diagrams or field change instructions	2
8. Effect mechanical, hydraulic, or pneumatic system field changes, related to internal guidance and control, to missile and missile equipment in accordance with field change instructions	2
9. Perform calibration and adjustments of missile-borne telemetering equipment on own ship or station	2
10. Perform electrical/electronic functional tests of missile system, using specialized test equipment; direct and coordinate operation of test equipment; observe time limits and dial reading tolerances; reject malfunctioning missiles	2
11. Perform and supervise all tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits	2

Qualifications for Advancement in Rating	Applicable Rates GS
102 MAINTENANCE AND/OR REPAIR—Continued	
12. Perform functional tests of missile internal guidance and control mechanical, hydraulic/pneumatic systems, using specialized and standard test equipment; adjust and aline components to conform to allowable limits· isolate and locate malfunctioning components: check test equipment for proper operation; coordinate and direct test equipment operators; replace or repair defective equipment, excluding tender/yard maintenance; determine signal inputs for measuring component responses	2
13. Perform missile electrical/electronic component tests, using specialized and standard test equipment; adjust and aline components to conform to allowable limits; isolate and locate malfunctioning components; check test equipment for proper operation; coordinate and direct test equipment operators; replace or repair defective equipment, excluding tender/yard maintenance; determine signal inputs for measuring component responses	1
14. Perform casualty analysis for malfunctioning electro-hydraulic or electro pneumatic systems associated with missile internal guidance and control (servo systems), using voltmeter, ohmmeter or multimeter, oscilloscope, special test equipment, and hand tools, check signals and continuity; measure voltages and pressures; disassemble units and make adjustments, replacements, or repairs, excluding tender/yard maintenance	1
15. Perform casualty analysis of malfunctioning electronic power supplies and regulators, using standard electronic test equipment; isolate, locate, and replace electronic packages, tubes, capacitors, and resistors; replace circuit components and fuses and resolder connections	1
16. Perform casualty analysis of free and rate gyroscopes, gyro control and autopilot systems; trace malfunctions from test data information by testing associated mechanical and electrical components for proper operation; check for proper gyro output	

Qualifications for Advancement in Rating	Applicable Rates GS
102 MAINTENANCE AND/OR REPAIR—Continued	
16—Continued	
signal; observe uncaging and erecting mechanism for proper operation; aline synchros to electrical zero; aline a servo indicating or setting system; replace malfunctioning gyroscopes	1
17. Perform delicate balancing and adjustment and alinement tests on electronic and electrical circuits and test equipment components; reduce data and make corrections; compare values, set predetermined values, and check responses	C
18. Analyze graphic recorder records	C
19. Perform casualty analysis of electrical/electronic malfunctioning missile and missile test equipment systems and components, on own ship or station; effect allowable repairs; determine results required and insure operation of components within allowable limits; retest to insure proper operation	C
20. Perform casualty analysis, related to internal guidance and control, of missile and missile test equipment, mechanical, hydraulic, and pneumatic malfunctioning components; check, adjust, and aline equipment and components to predetermined values; use all standard and specialized test equipment; replace parts or perform allowable repairs; determine results required and insure operation of components within allowable limits	C
21. Perform casualty analysis of malfunctioning missile-borne telemetering components, on own ship or station; analyze graphic recorder signals; calibrate and test frequency and proper operation of channels; isolate inoperative channels by making station checks; replace components which cannot be tuned within allowable limits	C
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Maintain required shop and equipment work logs; log work accomplished; record test data	3
2. Maintain electronic equipment histories	2
3. Prepare job orders and work requisitions	2

Qualifications for Advancement in Rating	Applicable Rates GS
103 ADMINISTRATIVE AND/OR CLERICAL—Continued	
4. Inspect work performed in preparation of missile internal guidance and control hydraulic and pneumatic systems for tests, and inspect associated test and auxiliary equipment for optimum operation of equipment	2
5. Inspect work performed in preparation for missile systems tests for missile electrical and electronic systems and associated electrical and electronic test equipment for optimum operation of equipment	2
6. Supervise handling and stowage of missile sections and missile components, direct movement of missile, missile sections, and components in transporting, placing on test stand, assembly rack, and stowage racks	1
7. Prepare reports covering missile electrical and electronic system and electrical and electronic test equipment; direct movement of missile, missile sections, and components in transporting, placing on test stand, assembly rack, and stowage racks	1
8. Supervise personnel in operation of missile electrical and electronic test equipment	1
9. Inspect work performed on missile-borne telemetering equipment, checking for proper performance of test and adjustment procedures and optimum operation of equipment, on own ship or station	1
10. Supervise and instruct personnel in charging internal guidance and control pressurized systems, replacement of parts and components, and performance of missile functional and systems tests	1
11. Inspect work performed in maintenance and repair of missile hydraulic or pneumatic systems for optimum operation of equipment	1
12. Supervise and instruct personnel in performance of missile system and component tests	C
13. Inspect work performed in maintenance and repair of electronic power supplies and regulators and electrohydraulic or electropneumatic systems included in missile internal guidance and control	C

Qualifications for Advancement in Rating	Applicable Rates GS
103 ADMINISTRATIVE AND/OR CLERICAL—Continued	
14. Organize work assignments and supervise personnel to accomplish maintenance projects as directed	C
15. Organize and maintain technical library of missile publications and other data required by technical bureau concerned	C
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Types and purpose of common tools used in assembly and disassembly of missile sections and missile containers	3
2. Purpose and application of desiccants in missile stowage; interpretation of desiccant colors	3
3. Types of information shown and meaning of electrical and electronic symbols used in schematic diagrams of missile equipment	3
4. Types of information shown and meanings of mechanical symbols used in schematic diagrams of missile equipment	3
5. Identification of parts using assembly drawings	3
6. Methods of resuscitation from electrical shocks, treatment for burns	3
7. Electrical, ordnance (solid propellant rocket motors, high-explosive warheads, igniters), fueling, high pressure air, hydraulic, and mechanical safety precautions	3
8. Types of missile guidance, stabilization, and propulsion systems	3
202 MAINTENANCE AND/OR REPAIR	
1. Types, structure, maintenance procedures, and electrical characteristics of batteries	3
2. Methods of cleaning commutators and commutator heads and precautions to be observed	3
3. Electrical and physical characteristics of electric motors, generators, and dynamotors	3
4. Soldering materials and methods used in maintenance and repair	3

Qualifications for Advancement in Rating	Applicable Rates GS
202 MAINTENANCE AND/OR REPAIR—Continued	
5. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3
6. Applications of the laws of magnetism to d. c. motors and generators	3
7. Meaning of:	
a. Conductors and insulators	3
b. Lines of force	3
c. Field intensity	3
d. Flux density	3
e. Permeability	3
f. Ampere-turns	3
g. Hysteresis and eddy currents	3
h. Self and mutual induction	3
i. Electromagnetic induction	3
j. Coulomb	3
k. Volt	3
l. Ampere	3
m. Ohm	3
n. Henry	3
o. Circular mil	3
p. Farad	3
q. Watt	3
r. Kilowatt	3
s. Power factor	3
t. Kilovolt-amperes	3
u. Reactance	3
v. Capacitance	3
w. Inductance	3
x. Impedance	3
y. Torque	3
z. Frequency	3
aa. Cycle	3
bb. Phase	3

Qualifications for Advancement in Rating	Applicable Rates GS
202 MAINTENANCE AND/OR REPAIR—Continued	
8. Function of the following measuring devices in electrical circuits:	
a. Ohmmeters	3
b. Meggers	3
c. Ammeters (a. c. and d. c.)	3
d. Voltmeters (a. c. and d. c.)	3
e. Frequency meters	3
f. Wheatstone bridge	3
g. Thermocouple instruments	3
9. Function of the following in hydraulic and pneumatic systems:	
a. Pneumatic gages	3
b. Check valves	3
c. Reducing valves	3
d. Safety valves	3
e. Restrictors	3
f. Actuators	3
g. Gaskets	3
h. "O" rings	3
i. Manifolds	3
j. Pressure regulators	3
k. Flow regulators	3
l. Micronic filters	3
m. Servo valves	3
10. Function of the following in electrical circuits:	
a. Resistors	3
b. Rheostats and potentiometers	3
c. Solenoids	3
d. Inductors	3
e. Capacitors	3
f. Fuses	3
g. Switches	3
h. Reactors	3
i. Transformers	3
j. Relays	3
k. Copper oxide rectifiers	3
l. Selenium rectifiers	3
11. RMA color coding systems for capacitors and resistors	3

Qualifications for Advancement in Rating	Applicable Rates GS
202 MAINTENANCE AND/OR REPAIR—Continued	
12. Relationship of length and cross-sectional area to resistance of a conductor	3
13. Relationship of temperature, pressure, and volume in gases	3
14. Relationship of resistance, temperature, and current in an electrical conductor	3
15. Calculate current, voltage, and resistance in d. c. series and parallel circuits containing not more than four elements	3
16. Relationship of resistance, inductance, and capacitance in a. c. circuits	3
17. Relationship of current, voltage, and impedance in a. c. circuits	3
18. Current, voltage, and impedance relationships in series and parallel resonant circuits	2
19. Calculate current, voltage, phase angle, impedance, and resonance in a. c. series and parallel circuits containing not more than a combination of four elements	2
20. Theory of permanent-magnet moving-coil meters with a knowledge of shunts and of multiplier resistors	2
21. Effects of meter sensitivity in circuit voltage measurement	2
22. Types and purpose of gas-filled tubes and cathode ray tubes	2
23. Purpose of diode, dry disk, and crystal rectifiers; purpose of triode, tetrode, and pentode vacuum tubes	2
24. Function of oscilloscope, tube tester, electronic voltmeter, signal generator, frequency meter, spectrum analyzer, pulse generator, impedance bridge, resistance bridge, RF wattmeter, and FM signal generator	2
25. Relationship of reluctance, flux, and magnetomotive force in a. c. and d. c. magnetic circuits	2
26. Function and operating characteristics of missile pneumatic systems and components	2
27. Function and operating characteristics of missile hydraulic systems and components	2

Qualifications for Advancement in Rating	Applicable Rates GS
202 MAINTENANCE AND/OR REPAIR—Continued	
28. Function and operating principles of check valves and solenoid operated valves in missile hydraulic and pneumatic systems	2
29. Function and operating principles of pressure regulators in missile hydraulic and pneumatic systems	2
30. Methods of adjusting flow and pressure regulators used in missile hydraulic and pneumatic systems	2
31. Function and operating principles of gear and piston type pumps used in missile hydraulic systems	2
32. Function and operating principles of solenoid-operated hydraulic actuators used in missile aerodynamic control systems	2
33. Proper method of locating casualties by localizing to main unit, subassembly, circuit, and component	1
34. Application and operating principles of wire and coaxial transmission lines and wave guides, T/R and AT/R tubes, klystrons, magnetrons, and crystal mixers	1
35. Proper method of making RF power measurements	1
36. Methods of coupling: Transformer, impedance, capacitance, resistive, and direct	1
37. Function and operating principles of half-wave, full-wave, and bridge-type rectifiers and voltage doublers; simple voltage regulators and gaseous-type regulator tubes; function of capacitor and choke input filters	1
38. Applications of low-pass, high-pass, and band-pass filters	1
39. Operating principles of diode, dry disk, and crystal rectifiers; function of each of the elements in gas-filled, vacuum, and cathode ray tubes	1
40. Functions and applications of servomechanisms and synchros as applied to missiles and missile test equipment	1
41. Methods of making gain, phase, balancing, and zeroing adjustments to servo loops found in missile internal guidance and stabilization systems	1
42. Function and physical and electrical characteristics of free and rate gyroscopes, including caging and erecting devices	1

Qualifications for Advancement in Rating	Applicable Rates GS
202 MAINTENANCE AND/OR REPAIR—Continued	
43. Function and general operation of missile fuel systems	1
44. Electrical characteristics of Hertz, Marconi, and dipole antennas. Principles of operation of dish reflectors and of parasitic reflectors and directors	C
45. Operating principles of modulation: Amplitude, frequency, phase, and pulse	C
46. Operating principles of the following:	
a. Tuned coupling circuits	C
b. Impedance matching	C
c. Phase shifters	C
d. Audio amplifiers	C
e. RF amplifiers	C
f. Video amplifiers	C
g. Cathode followers	C
h. Oscillators: Hartley crystal-controlled, Colpitts, TPTG, and electron-coupled	C
i. Diode and crystal detectors	C
j. Modulators	C
k. Differentiators	C
l. Integrators	C
m. Blocking oscillators	C
n. Trigger circuits and multivibrators	C
o. Coincidence circuits	C
p. Limiters	C
q. Clippers	C
r. Discriminators	C
s. AGC circuits	C
t. AFC circuits	C
u. Counting circuits	C
v. Sawtooth generators	C
w. Peakers	C
x. Clampers	C
203 ADMINISTRATIVE AND/OR CLERICAL	
1. System of assigning "AN" letter-number combination as designation for electronic equipment	3

Qualifications for Advancement in Rating	Applicable Rates GS
203 ADMINISTRATIVE AND/OR CLERICAL—Continued	
2. Types of information found in BuOrd Instructions and Notices and NavOrd Allowance Lists; purpose and scope of BuOrd Manual as stated in chapter 1	2
3. Application of allowance lists in determining spare parts, tools, and supplies kept on board	1
4. Procedures for obtaining replacement parts and supplies; maintenance of inventory	1
300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER	
Guided Missilemen advance to Warrant Control Ordnance Control Technician and/or to Limited Duty Officer, Ordnance. As an alternate, Guided Missilemen advance to Warrant Electronics Technician and/or to Limited Duty Officer, Electronics.	

APPENDIX III

AN NOMENCLATURE SYSTEM

The AN letter-number system is used to identify the various kinds and models of electronic apparatus employed by the Army, the Navy, and the Air Force. Separate types of designations are used for complete installations of a particular equipment and for major components of the device. The basic designation for a complete instalation is considered first.

An indicator for a complete installation begins with the letters AN. (The letters AN are an abbreviation for Army-Navy, but does not mean that the Army or Navy utilizes the equipment.) This is followed by a slant bar and a three-letter group. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment respectively. Following the three-letter group is a number which indicates the specific model of the equipment.

An example of a basic designation is AN/APG–30. The letters following the slant bar have the meanings given in table 1.

Using the example AN/APG–30, the symbols are interpreted as follows: AN signifies a complete installation. In the three-letter group, the first letter, A, in the first or "Installation" column, indicates airborne equipment. The second letter, P, is in the "Type of Equipment" column; therefore, it indicates radar equipment. The letter G in the "Purpose" column refers to fire control or search light directing equipment. Examination of the *Handbook of Operating or Service Instructions* will give further information on the exact purpose of the equipment.

The number 30 following the letters of the second group is the model number of the set. If the basic model is modified, the new model is given an additional letter such as A, B, or C, following the model number. For example, AN/APG–30A is a modification of the basic AN/APG–30 model. The next modification is labeled AN/APG–30B.

When the system just described is applied to subassemblies or major components of the complete installation, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of component in question.

Table 1.—Set or equipment indicator letters.

Installation	Type of equipment	Purpose
A—Airborne (installed and operated in aircraft).	A—Invisible light, heat radiation.	A—Auxiliary assemblies (not complete operating sets).
B—Underwater mobile, submarine.	B—Pigeon.	B—Bombing.
D—Pilotless carrier.	C—Carrier.	C—Communications (receiving and transmitting).
F—Fixed.	D—Radiac.	D—Direction finder.
G—Ground, general ground use (includes two or more ground installations).	E—Nupac (nuclear protection and control).	E—Ejection and/or release.
K—Amphibious.	F—Photographic.	G—Fire control or searchlight directing.
M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).	G—Telegraph or teletype.	H—Recording and/or reproducing (graphic, meteorological, and sound).
P—Pack or portable (animal or man).	I—Interphone and public address.	M—Maintenance and test assemblies (including tools).
S—Water surface craft.	J—Electromechanical (not otherwise covered).	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing).
T—Ground, transportable.	K—Telemetering.	Q—Special or combination of purposes.
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground).	L—Countermeasures.	R—Receiving, passive detecting.
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).	M—Meteorological.	S—Detecting and/or range and bearing.
W—Water; surface and undersurface.	N—Sound in air.	T—Transmitting.
	P—Radar.	W—Control.
	Q—Sonar and underwater sound.	X—Identification and recognition.
	R—Radio.	
	S—Special types (magnetic, etc.) or combination of types.	
	T—Telephone (wire).	
	V—Visual and visible light.	
	W—Armament (peculiar to armament, not otherwise covered).	
	X—Facsimile or television.	

Table 2 gives the component indicator, family name, and examples of use. An example of this type of component is:

AS–629/APQ–50—Antenna, complex No. 629, part of radar set AN/APQ–50.

A unit that is not a part of any complete installation but may be used with many installations also is found in table 2. An example of this type of unit is:

TS–352/U—Test item, multimeter No. 352 for general utility use.

Table 2.—Component indicators.

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
AB	Supports, Antenna	Antenna mounts, mast bases, mast sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennae, Complex	Arrays, parabolic type, masthead, etc.
AT	Antennae, Simple	Whip or telescopic, loop, dipole, reflector, etc.
BA	Battery, primary type.	B batteries, battery packs, etc.
BB	Battery, secondary type.	Storage batteries, battery packs, etc.
C	Controls	Control box, remote tuning control, etc.
CG	Cable Assemblies, RF.	RF cables, wave guides, transmission lines, etc. with terminals.
CK	Crystal kits	A kit of crystals with holders.
CM	Comparators	Compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating, regulating, or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Couplers	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic).	Electronic apparatus for changing the phase, frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable Assemblies, Non-RF.	Non-RF cables with terminals, test leads, also composite cables of RF and non-RF conductors.
CY	Cases and Cabinets	Rigid and semirigid structure for enclosing or carrying equipment.
DA	Load, Dummy	RF and non-RF test loads.

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
DT	Detecting Heads	Magnetic pickup device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FR	Frequency Measuring Devices.	Frequency meters, tuned cavity, etc.
G	Generators, Power	Electrical power generators without prime movers. (See PU & PD.)
HD	Air Conditioning Apparatus.	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, Non-Cathode-Ray Tube.	Calibrated dials and meters, indicating lights, etc. (See IP.)
IL	Insulators	Strain, stand-off, feed-through, etc.
IM	Intensity Measuring Devices.	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, Cathode-Ray Tube.	Azimuth, elevation, panoramic, etc.
J	Junction Devices	Junction, jack and terminal boxes, etc.
KY	Keying Devices	Mechanical, electrical, and electronic keyers, coders, interrupters, etc.
MD	Modulators	Device for varying amplitude, frequency or phase.
ME	Meters, Portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or Magnetic Field Generators.	Magnetic tape or wire eraser, electromagnet, permanent magnet, etc.
MK	Miscellaneous Kits	Maintenance, modification, etc., except tool and crystal. (See CK, TK.)
ML	Meteorological Devices.	Barometer, hygrometer, thermometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified. Do not use if better indicator is available.

Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
O	Oscillators	Master frequency, blocking, multivibrators, etc. (For test oscillators, see SG.)
OA	Operating Assemblies	Assembly of operating units not otherwise covered.
OS	Oscilloscope, Test	Test Oscilloscopes for general test purposes.
PP	Power Supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PU	Power Equipments	Rotating power equipment except dynamotors. Motor-generator, etc.
R	Receivers	Receivers, all types except telephone.
RE	Relay Assemblies	Electrical, electronic, etc.
RF	Radio Frequency Component.	Composite component of RF circuits. Do not use if better indicator is available.
RG	Cables, RF, Bulk	RF cable, wave guides, transmission lines, etc. without terminals.
RT	Receiver and Transmitter.	Radio and radar transceivers, composite transmitter and receiver, etc.
SA	Switching Devices	Manual, impact, motor driven, pressure operated, etc.
SG	Signal Generators	Test oscillators, noise generators, etc. (See O.)
SM	Simulators	Flight aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
T	Transmitters	Transmitters, all types except telephone.
TD	Timing Devices	Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning Devices	Tilt and/or train assemblies.
TK	Tool Kits	Miscellaneous tool assemblies.
TL	Tools	All types except line construction.

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
TN	Tuning Units	Receiver, transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phono pickups, sonar transducers, vibration pickups, etc.
TS	Test Items	Test and measuring equipment not otherwise included; boresighting and alinement equipment.
TV	Tester, Tube	Electronic tube tester.
TW	Tapes and Recording Wires.	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, Audio and Power.	Unions, plugs, sockets, adapters, etc.
UG	Connectors, RF	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
ZM	Impedance Measuring Devices.	Used for measuring Q, C, L, R or PF, etc.

ADDITIONAL DESIGNATORS

In order to identify experimental equipment, a designator is added to parentheses to the basic symbols. An example is AN/ARC–3 (XB–1). The letter X within the parentheses indicates experimental equipment, the second letter identifies the research organization carrying out the experimental development, and the number reveals the particular set developed. When the set has been accepted for general use, the experimental designator is dropped and the basic symbols are used thereafter.

A set designed for training purposes is assigned type numbers as follows:

Equipment designed to train personnel in the use of a specific model is assigned a designator consisting of the basic set symbol followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–6A–T1 is the first training set associated with Radio Set AN/ARC–6A.

Models designed to train personnel in the use of general types of equipment are assigned the basic type indicator followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–T1 is the first training set used for instruction in the general use of airborne radio communication installations.

APPENDIX IV

GLOSSARY OF GUIDED MISSILE TERMS

ACCELERATION, LATERAL. The component of the linear acceleration of an aircraft along its "lateral" or "Y" axis.

ACCELERATION, LONGITUDINAL. The component of linear acceleration of an aircraft parallel to its "longitudinal" or "X" axis.

ACCELERATION, NORMAL. (1) The component of the linear acceleration of an aircraft along its "normal" or "Z" axis. (2) The usual or typical acceleration.

ACCELERATION, PITCH. The angular acceleration of an aircraft about its "lateral" or "Y" axis.

ACCELERATION, ROLL. The angular acceleration of an aircraft about its "longitudinal" or "X" axis.

ACCELERATION, YAW. The angular acceleration of an aircraft about its "normal" or "Z" axis.

ACCELEROMETER. An instrument that measures one or more components of the accelerations of a vehicle.

ACCUMULATOR, PRESSURE. An apparatus for storing fluid under pressure, usually consisting of a chamber separated into a gas compartment and a fluid compartment by a diaphragm. Fluid stored in accumulators is used to actuate pressure-operated devices, such as flaps, wings etc.

ACOUSTIC VELOCITY. The speed of sound, or similar pressure waves.

AERODYNAMICS. That field of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

AFTERBURNING. (1) The characteristic of certain rocket motors to burn regularly for some time after the main burning and thrust have ceased. (2) The process of fuel injection and combustion in the exhaust jet of a turbo-jet engine (after the turbine).

AILERON. A hinged or movable surface on an airframe, the primary function of which is to induce a rolling moment on the airframe. It usually is part of the trailing edge of a wing.

AIRCRAFT. Any weight-carrying structure for navigation of the air, designed to be supported by buoyancy of the structure, or by the dynamic action of the air against its surfaces.

AIRFOIL. A thin body, such as a wing, aileron, or rudder, designed to obtain reaction from the air through which it moves.

AIRFOIL SECTION. A cross section of an airfoil parallel to the plane of symmetry or to a specified reference plane.

AIRFRAME. Concerning guided missiles, the assembled principal structural components, less propulsion system, control and electronic equipments, and payload.

AIR SPEED, TRUE. Calibrated air speed corrected for altitude effects, i. e., pressure and temperature, and for compressibility effects where high speeds are concerned. Not to be confused with ground speed.

AMBIENT. Environmental conditions; may pertain to pressure, temperature, etc.

ANGLE, AILERON. The angular displacement of an aileron from its neutral position. It is positive when the trailing edge of the right aileron is below the neutral position.

ANGLE, CRAB. The angle between the direction in which an aircraft is heading and its true course.

ANGLE, DEPRESSION. The angle measured downward from the horizontal to the axis of an airborne radar beam directed at a target. This is the complement of the incidence angle of the beam at the target plane.

ANGLE, DIHEDRAL. A dihedral angle is formed by two intersecting planes. In aeronautical usage one of these is the perpendicular to the plane of symmetry and parallel to the longitudinal axis of the airframe, and the other is a plane containing the wing axis and the longitudinal axis of the airframe.

ANGLE, DRIFT. The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

ANGLE, ELEVATOR. The angular displacement of the elevator from its neutral position. It is positive when the trailing edge of the elevator is below the neutral position.

ANGLE, FLIGHT PATH. The angle between the flight path of an aircraft and the horizontal. Sometimes called FLIGHT PATH SLOPE.

ANGLE, GLIDING. The angle between the flight path during a glide and a horizontal axis fixed relative to the earth.

ANGLE OF ATTACK. The angle between a reference line fixed with respect to an airframe and the apparent relative flow line of the air.

ANGLE OF ATTACK, ABSOLUTE. The angle of attack of an airfoil, measured from the attitude of zero lift.

ANGLE OF ATTACK, CRITICAL. The angle of attack at which the flow about an airfoil changes abruptly, as evidenced by abrupt changes in the lift and drag.

ANGLE OF CANT. In a spin-stabilized rocket, the angle formed by the axis of a venturi and a line parallel to the longitudinal axis of the rocket.

Angstrom Unit. A unit of length equal to one ten-thousandth of a micron, or one hundred-millionth of a centimeter. Used to express lengths of extremely short waves.

Arming. As applied to fuzes, the changing from a safe condition to a state of readiness for initiation. Generally a fuze is caused to arm by acceleration, rotation, clock mechanism, air travel, or by combinations of these.

Artificial Horizon. (1) A device that indicates the attitude of an aircraft with respect to the true horizon. (2) A substitute for a natural horizon, such as a liquid level, pendulum, or gyroscope, incorporated in a navigating instrument.

Attitude. The position of an aircraft as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

Automatic Pilot. An automatic control mechanism for keeping an aircraft in level flight and on a set course or for executing desired maneuvers. Sometimes called GRYOPILOT, MECHANICAL PILOT, ROBOT PILOT, or AUTOPILOT.

Autosyn. A Bendix-Marine trade name for a synchro, derived from the words "AUTOmatically SYNchronous." (See Synchro.)

Axes of an Aircraft. Three fixed lines of reference, usually centroidal and mutually perpendicular. The horizontal axis in the plane of symmetry, usually parallel to the axis of the propeller shaft or the thrust line of the jet motor, is called the LONGITUDINAL AXIS; the axis perpendicular to this, in the plane of symmetry, is called the NORMAL or YAW AXIS; and the third axis perpendicular to the other two is called the LATERAL or PITCH AXIS. In mathematical discussion, the first of these axes, drawn from rear to front, is generally designated the "X" axis; the second, drawn downward, the "Z" axis; and the third, running from left to right, the "Y" axis.

Azimuth. A direction expressed as a horizontal angle usually in degrees or mils and measured clockwise from north. Thus azimuth will be true azimuth, grid azimuth, or magnetic azimuth depending upon which north is used.

Bank. To incline an aircraft laterally; i. e., to rotate it about its longitudinal axis.

Beacon, Radar. Generally a nondirectional radiating device, containing an automatic radar receiver and transmitter, that receives pulses (interrogation) from a radar, and returns a similar pulse or set of pulses (response). The beacon response may be on the same frequency as the radar, or may be on a different frequency.

Beamwidth. The angular separation in azimuth between the two directions to the right and left of the nose of the beam, at which the gain is one-half that at the nose. Beamwidth may be measured also in elevation, in the vertical plane, or in an inclined plane.

Bolometer. (1) A very sensitive type of metallic resistance thermometer, used for measurements of thermal radiation. (See Detector Infrared.) (2) In electronics, a small resistive element capable of dissipating microwave power, using the heat so developed to effect a change in its resistance, thus serving as an indicator; commonly used as a detector in low- and medium-level power measurement.

Booster. (1) A high-explosive element sufficiently sensitive to be actuated by small explosive elements in a fuze and powerful enough to cause detonation of the main explosive filling. (British—GAINE) (2) An auxiliary propulsion system which travels with the missile and which may or may not separate from the missile when its impulse has been delivered. A booster system may contain or consist of one or more jatos. (See Jato.)

Burn Out. (1) To overheat a combustion chamber or nozzle to such an extent that the walls weaken and rupture. (2) The time at which a jet motor ceases to burn. (See Brennschluss.)

Camber. The rise of the curve of an airfoil section, usually expressed as the ratio of the departure of the curve from a straight line joining the extremities of the curve to the length of this straight line. UPPER CAMBER refers to the upper surface; LOWER CAMBER refers to the lower surface; and MEAN CAMBER to the mean line of the section. Camber is positive when the departure is upward and negative when it is downward.

Catapult. A fixed structure which provides an auxiliary source of thrust to a missile or aircraft; must combine the function of directing and accelerating the missile during its travel on the catapult; serves the same function for a missile as does a gun tube for a shell. (See Launcher.)

Cavitation. The formation and collapse of vapor pressure bubbles owing to the movement of a body, or the effects of this action.

Channel, Telemeter. Designates the complete route for transmission of a telemetered function, including pick-up, commutator, modulator, transmitter, receiver, demodulator, decoder, and recorder.

Clamping Circuit. A circuit which maintains either amplitude extremity of a waveform at a certain level of potential.

Clipping Circuit. In electronics, a pulse-shaping network which removes that part of a waveform which tends to extend above (or below) a chosen voltage level.

Clutter, Radar. The visual evidence on the radar indicator screen of sea-return or ground-return which, if not of particular interest, tends to obscure the target indication.

Computer. A mechanism that performs mathematical operations.

Computer, Analogue. A computer in which quantities and relationships are represented by continuously variable physical quantities such that approximate solutions can be obtained readily.

Computer, Digital. A computer in which quantities are represented in numerical form and which generally is made to solve complex mathematical problems by iterative use of the fundamental processes of addition, subtraction, multiplication, and division.

Conical Scanning. Defines a radar scanning system wherein a point on the radar beam describes a circle at the base of a cone, and the axis is the generatrix of the cone.

Control. (1) Concerning missiles in general, the entire processes of intelligence and maneuver intended for reaching a specified destination, and special connotation on changes in course owing to data which may be observed and computed either in the missile or externally. (2) Concerning an airframe, a device for effecting a change in motion.

Control, Bang-bang. A control system used in guidance, wherein the corrective control applied to the missile is always applied to the full extent of servo motion.

Control-Plane. The qualifying term that describes the transmitting antenna on an aircraft that radiates the control signal by which a guided bomb is steered.

Control, Proportional. Control in which the action to correct an error is made proportional to that error.

Control Surface. A movable airfoil designed to be rotated or otherwise moved by control servomechanism in order to change the attitude of the aircraft.

Controllability. The quality of an aircraft that determines the ease of operating its control and/or the effectiveness of displacement of the controls in producing change in its attitude in flight.

Crystal, Piezoelectric. A crystal that, when strained, produces on its surface an electric charge; or that will deform or bend when a voltage is applied properly. When driven by an alternating voltage at proper frequency, as determined by the dimensions, material, and axes of crystal, it will resonate and stabilize the applied frequency.

Damping. The effect of friction or its equivalent in reducing oscillation of a system.

DECIBEL. A unit for expressing the magnitude of a change in sound or electrical power level. One decibel (db) is approximately the amount that the power of a pure sinewave sound must be changed in order for the change to be just barely detectable by the average human ear. Precisely, the difference in decibels between two signals is 10 times the logarithm of the ratio of the voltages. Unless the reference is specified, decibels represent merely a logarithmic ratio. A common reference level is zero db with one milliwatt into a 600-ohm load.

DETECTOR, INFRARED. Thermal devices for observing and measuring infrared radiation, such as the volometer, radiomicrometer, thermopile, pneumatic cell, photocell, photographic plate, and photoconductive cell.

DETONATION. A sudden and violent explosion. Detonation is practically instantaneous. The slower burning of some explosives is called DEFLAGRATION.

DETONATOR. An explosive device, sensitive to electrical or mechanical impulse. Generally used to set off a larger quantity of explosive.

DIELECTRIC. A substance capable of sustaining an electric field and of undergoing polarization. All electric insulators are dielectrics.

DIFFERENTIATING CIRCUIT. A circuit that produces an output voltage substantially in proportion to the rate of change of the input voltage or current.

DIFFUSER. A duct of varying cross section designed to convert a high-speed gas flow into low-speed flow at an increased pressure.

DISCRIMINATOR. A device used to convert input frequency changes to proportional output voltages. For example, in a radio receiver, the stage that converts the frequency-modulated signals directly to audio-frequency signals.

DITHER. A signal of controlled amplitude and frequency applied to the servomotor operating a transfer valve, such that the transfer valve is constantly being "quivered" and cannot stick at its nulled position.

DIVE. (1) A steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight. (2) In stress analysis, a design condition for the wings representing a steady state of flight characterized by high speed and an angle of attack approximately that of zero lift. (See Pull-Up.)

DOPPLER EFFECT. The apparent change in frequency of a sound or radio wave, reaching an observer or a radio receiver, caused by a change in distance or range, between the source and the observer or the receiver during the interval of reception.

DRAG. That component of the total air forces on a body, in excess of the forces owing to ambient atmosphere, and parallel to the relative gas stream but opposing the direction of motion. It is composed of skin-friction-, profile-, induced-, interference-, parasite-, and base-drag components.

DRAG-WEIGHT RATIO. The ratio of the drag of a missile to its total weight.

DRONE. A remotely controlled aircraft.

DUTY CYCLE. In electronics, the ratio of the pulse duration time to the pulse repetition time.

DYNAMOTOR. A combination electric motor and d-c generator having two or more separate armature windings and a common set of field poles. One armature winding, receiving direct current, operates as a motor producing rotation, while others operate as a dynamo or generator, generating voltage.

ELECTROMAGNETIC. Pertaining to the combined electric and magnetic fields associated with radiation or with movements of charged particles.

ELEVATOR. A movable auxiliary airfoil, the function of which is to impress a pitching moment on the aircraft. It is usually hinged to the stabilizer.

ELEVONS. Wing flaps combining the functions of ELEVATORS and ailerons.

EMMISIVITY. The rate at which the surface of a solid or a liquid emits electrons when additional energy is imparted to the free electrons in the material by the action of heat, light, or other radiant energy or by the impact of other electrons on the surface.

ENVELOPE. In electronics—(1) The glass or metal housing of a vacuum tube; (2) a curve drawn to pass through the peaks of a graph showing the waveform of a modulated radio-frequency carrier signal.

ERROR SIGNAL. (1) In servomechanisms, the signal, frequently a voltage, applied to the control circuit that indicates the misalignment between the controlling and the controlled members. (2) In tracking systems, a voltage, depending upon the signal received from the target, whose sign and magnitude depends on the angle between the target and the center of the scanning beam.

E-VECTOR. The vector representing the electric field of an electromagnetic wave. In free space it is perpendicular to the direction of propagation.

FEEDBACK. The electrical or acoustical return of a portion of the amplifier stage output to the input of that stage, or a preceding stage, such that there is either increase or reduction in amplification depending upon the relative phase of the return with the input signal.

Filter. In electricity, a device or selective circuit network designed to pass signals within a specified frequency range while greatly reducing the amplitudes of signals of undesired frequencies.

Frequency, Carrier. The frequency of the unmodulated radio wave emanated from a radio, radar, or other type transmitter.

Frequency, Electronic. The number of recurrences of a periodic phenomenon in a unit of time. In specifying electrical frequency, the customary unit of time is the second. For example, 15 kc is understood to mean 15,000 cycles per second. A list of the frequency designations follows:

Designation of frequency	*Authorized abbreviation*	*Frequency in kc*
Very low	vlf	Below 30.
Low	lf	30 to 300.
Medium	mf	300 to 3000.
High	hf	3000 to 30,000.
Very high	vhf	30,000 to 300,000.
Ultrahigh	uhf	300,000 to 3,000,000.
Superhigh	shf	3,000,000 to 30,000,000.
Extremely high	ehf	30,000,000 to 300,000,000.

Frequency, Infrared. The range of invisible radiation frequencies that adjoins the visible-red spectrum and extends to microwave radio frequencies.

Frequency, Pulling. The tendency of any load to change the frequency of an oscillator.

Frequency, Subcarrier. In telemetering, an intermediate frequency that is modulated by intelligence signals and, in turn, is used to modulate the radio carrier either alone or in conjunction with subcarriers on other channels.

Fuselage. The body of approximately streamline form to which the wings and tail unit of an aircraft are attached.

Fuse. A device designed to initiate a detonation under the conditions desired such as by impact, elapsed time, proximity, or command.

Gate. (1) In radar or control terminology, an arrangement to receive signals only in a small, selected fraction of the principal time interval. (2) Range of air-fuel ratios in which combustion can be initiated.

Gimbal. A mechanical frame containing two mutually perpendicular intersecting axes of rotation (bearings, shafts, or both).

Glide. To descend at a normal angle of attack with little or no thrust.

Glide Bomb. A winged missile powered by gravity. The wing loading is so high that it is incapable of flight at the speeds of conventional bombardment aircraft. Such a missile therefore must be carried rather than towed.

Glint. The pulse-to-pulse variation in amplitude of reflected radar signal, owing to the reflection of the radar beam from a body which is changing its reflecting surface in an extremely rapid manner, such as would exist in pulses reflected from a rapidly spinning airplane propeller.

Ground Speed. The horizontal component of the velocity of an aircraft relative to the ground.

Ground Wave. A radio wave propagated over the surface of the earth.

Group. In telemetering, designates a number of subcarrier oscillators.

Guidance. Concerning missiles, the entire processes of intelligence and of maneuver intended for reaching a specified destination, with special connotation on the flight path and on the information for determining the proper course.

Guided Missile. An unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle.

Gyroscope. A wheel or disk, mounted to spin rapidly about an axis and also free to rotate about one or both of two axes perpendicular to each other and to the axis of spin. The spinning gyroscope either offers considerable resistance, depending upon its angular momentum to any torque, which would tend to change the direction of the spin axis or, if free, changes its spin axis in a direction perpendicular both to the torque and to the original spin axis.

Gyroscope, Directional. A gyroscopic instrument for indicating direction, containing a free gyroscope which holds its position in azimuth and thus indicates angular deviation from the course.

Gyroscope, Free. A gyroscope mounted in two or more gimbal rings so that its spin axis is free to maintain a fixed orientation in space.

Gyroscope, Rate. A gyroscope with a single gimbal mounting such that rotation about an axis perpendicular to the axis of the gimbal and to the axis of the gyro produces a precessional torque proportional to the rate of rotation.

Gyroscopic Horizon. A gyroscopic instrument that indicates the lateral and longitudinal attitude of the airplane by simulating the natural horizon.

Hangfire. The delayed ignition of the propellant or the igniter.

Hunting. A condition of instability resulting from over-correction by a control device and resultant fluctuations in the quantity intended to be kept constant.

H–Vector. The vector representing the magnetic field of an electromagnetic wave. In free space it is perpendicular to the E–vector and to the direction of propagation.

HYPERSONIC. See Sonic, Hyper.

INCLINOMETER. An instrument that measures the attitude of an aircraft with respect to the horizontal.

INTEGRATING CIRCUIT. A circuit whose output voltage is proportional to the product of the instantaneous applied input voltages and their duration. Some integrating circuits are made to give output proportional to input frequency and amplitude.

INTERFERENCE. (1) The aerodynamic influence of two or more bodies on one another. (2) In physics, the effect of superimposing two or more trains of waves. The resulting amplitude is the algebraic sum of the amplitudes of the interfering trains. When two sets of spherical waves interfere, a system of stationary nodes and antinodes is formed, which in optics is known as INTERFERENCE FRINGES. (See Interferometer.) (3) In radio communication, the disturbance of reception owing to strays or undesired signals. (4) In radar, confusing signals accidentally produced on the indicator by the effects of either friendly or enemy electrical apparatus or machinery or by atmospheric phenomena.

INTERFEROMETER. An apparatus used to produce and show interference between two or more wave trains coming from the same luminous area, and also to compare wavelengths with observable displacements or reflectors, or other parts, by means of interference fringes. An interferometer is frequently used to obtain quantitative information on flow around bodies in wind tunnels. (See Interference.)

IONOSPHERE. That portion of the earth's atmosphere, beginning about 30 miles above the earth's surface, which consists of layers of highly ionized air capable of bending or reflecting certain radio waves back to the earth.

KLYSTRON. A vacuum tube for converting direct-current energy into radio-frequency energy by alternately slowing down and speeding up an electron beam, utilizing the transit time between two points to produce a velocity-modulated electron stream to deliver radio-frequency power to a cavity resonator. The term is applicable to an ultrahigh-frequency amplifier, or generator, that combines the velocity-modulation principle with one or more cavity resonators to produce and/or utilize a velocity-modulated beam of electrons.

LATITUDE. The range in brightness of a scene over which fidelity of response of a television pick-up tube (or photographic emulsion) is maintained.

LAUNCHER. A mechanical structure that contrains a missile to move in the desired direction of flight during initial motion but does not itself propel the missile. (See Catapult.)

LAUNCHER, ZERO LENGTH. A launcher that supports the missile in the desired attitude prior to ignition, but which exercise negligible control on the direction of the missile's travel after ignition.

LEAD PREDICTION. The act of directing a missile (or projectile) ahead of a moving target—leading in aim—to a predicted collision point.

LEVELING CIRCUIT. An RC filter circuit used to level out fluctuations of a bias voltage.

LIMITER. In electronics, a circuit that limits the maximum positive or negative values of a waveform to some predetermined amount. It is used in frequency modulation systems to eliminate unwanted variations of amplitude in received waves.

LINEAR. A linear relationship exists between two quantities when the change in one quantity is exactly proportional to the change in the other quantity.

LOBE. One of the three-dimensional portions of the radiation pattern of a directional antenna.

LOBE, SLIDE. A portion of the radiation from an antenna outside the main beam and usually of much smaller intensity. A slide lobe is a region between two minima in the pattern.

LOCAL SPEED OF SOUND. The velocity of propagation of acoustic waves over a small region as determined by the conditions there.

LORAN.—An electronic navigation system in which two or more fixed transmitting stations utilize a pulse transmission technique. Aircraft and surface vessels, receiving the transmitted signals, may determine ranges to the stations, and thereby establish the location of the receiver. Derived from LONG RANGE NAVIGATION. (See Navigation, Hyperbolic.)

LUBBER MARK. A mark on the casing of a compass that gives the heading of an aircraft or vessel carrying the compass.

MACH NUMBER. The ratio of the velocity of a body to that of sound in the medium being considered. Thus, at sea level, in air at the Standard U. S. Atmosphere, a body moving at a Mach number of one (M=1) would have a velocity of approximately 1116.2 ft/sec (the speed of sound in air under those conditions).

MAGIC TEE. A particular radar waveguide configuration, so-called because its physical aspect resembles a double letter "T". The use of this configuration permits the coupling of a radar transmitter and receiver to a common antenna without the use of an anti-TR box.

MAGNETROMETER. An instrument for measuring the magnitude and direction of the earth's magnetic field or other types of magnetic fields.

MAGNETROSTRICTION. The change in the dimensions of a ferromagnetic object when placed in a magnetic field.

Modulation, Amplitude. A method of modulating a radio-frequency carrier by causing the amplitude of the carrier to vary above and below its normal value in accordance with the audio or other signal to be transmitted. The frequency of the carrier remains constant. Commonly abbreviated as a-m.

Modulation, Frequency. A method of modulating a radio-frequency carrier by causing the frequency of this carrier to vary above and below the no-modulated value, at a rate determined by the audio or other modulating signal to be transmitted. The amplitude of the carrier remains constant. Commonly abbreviated as f-m.

Modulation, Velocity. A form of modulation in which the electrons of a stream are speeded up and slowed down so as to produce bunches or groups.

Modulator, Balanced. In electronics, a circuit arrangement in which a carrier frequency is controlled by a signal wave in a manner to generate the side-band frequencies but to suppress the carrier in the output.

Motorboating. An audio system is said to be "motor-boating" when it emits pulsating audio sounds resembling those made by a motorboat. These pulsating sounds are caused by feedback at audio-frequency in the amplifier or receiver.

Navigational, Celestial. Navigation by means of observations of celestial bodies. A system wherein a missile, suitably instrumented and containing all necessary guidance equipment, may follow a predetermined course in space with reference primarily to the relative positions of the missile and certain preselected celestial bodies. Determination of the vertical to the earth's surface may be necessary in addition.

Navigation, Hyperbolic. A general method for determining lines of position by measuring the difference in distance of the navigator or navigating apparatus from two or more stations of known position. The difference in distance is determined by measuring the difference in time of arrival of signals transmitted from two or more stations. Although a great variety of signaling methods are theoretically possible, only radio waves are now commonly used in hyperbolic navigation. One system, using continuous wave signals, is known as DECCA. LORAN and GEE are systems using signals transmitted as pulses. One transmitting station is the master station, with the other station or stations, separated from 75 miles to 1,200 miles, being slave stations. The cycle of transmission always begins at the master station and the signal travels out in all directions. The arrival of the master signal at the slave station "triggers off" the slave which, in turn, transmits a signal. Points of constant difference in time of arrival of the two or more signals

will fall on hyperbolas, with the transmitters at the foci. The accuracy of the line of position that can be established by the navigator or the navigating apparatus varies from 200 yards to 2 miles depending upon the distance of the observer or the receiver from the baseline between stations and upon the type of system and equipment used. Although the navigator's equipment differs in details for GEE, DECCA, and LORAN; nevertheless, the fundamental characteristics are all the same. In the DECCA and GEE systems, the master station operates in conjunction with two or more slave stations. In the LORAN system, the master station operates with one slave station. SHORAN is a short-range system.

NOISE LEVEL. The strength of noise signals at a particular point in the electronic circuit; usually expressed in microvolts or in decibels with respect to some arbitrary level such as signal voltage or power.

NULL. Used in the electrical and electronics fields to mean zero.

NUTATION. The oscillation of the axis of a rotating body. In radar, the familiar situation in which, with the radar reflector stationary, the center of the dipole, which has its longitudinal axis fixed, is caused to describe a circle centered at the focus of the paraboloid and lying in a plane perpendicular to the axis of the paraboloid.

ORTHOGONAL. The property of being at right angles or, more generally, independent. Examples: The X, Y, and Z directions, or the R, $\emptyset$, and θ directions in the polar coordinates are orthogonal. Functions represented by the electric intensities of two radio signals, the ratio signals, the ratio of whose frequencies is irrational, are orthogonal.

OSCILLATOR, MAGNETOSTRICTION. An oscillator whose frequency is controlled by a magnetostrictive resonator.

OSCILLOGRAPH. A device for making a graphic record of the instantaneous values of a rapidly varying electric quantity as a function of time or some other quantity.

PAD. (1) A nonadjustable attenuator. (2) A permanent or semipermanent base constructed to support a missile-launching device.

PARAMETER. A quantity that may have various values each fixed within the limits of a stated case or discussion.

PAYLOAD. Warhead, fuze, and container. In the case of research and test vehicles, this includes equipment for taking data and transmitting or recovering it.

PHASE. A quantity that specifies a particular stage of progress in any recurring operation, such as a vibration or an alternating current. Phase is often expressed as an angle or a part of a circle in which case the complete cycle of operation is equal to 360° (one complete rotation). When two alternating quantities pass through corresponding zero values at the same time, they are said to be in phase.

Phosphors. Materials used in coating the viewing screen in radar, or other cathode-ray, indicator tubes, to transform the energy of the electron beam into visible light. In use are two types—(1) the single-layer (short-persistence) phosphor producing visible green light of rapid decay (to about 1 percent of initial value in about 0.05 sec); (2) the double-layer cascade (long-persistence) phosphor producing visible yellow light with a decaying time of several seconds.

Photography, Shadow. An optical system for recording shadows, generally utilizing a short, high-intensity light source. When used in supersonic wind tunnel work, photographs secured by this method reveal the locations and relative intensities of shock waves. Shadowgraphs are primarily sensitive to the second derivative of the densities existing in a supersonic stream over a model, and thereby reveal sharp changes in density as in shock waves. (See Schlieren).

Pick-up. In telemetering, a sensing instrument to measure a varying quantity, such as a pressure gage, a strain-gage element, position indicator, etc; also called END INSTRUMENT.

Piezoelectric. The property of certain crystals in developing electrical charge or potential difference across certain crystal faces when subjected to a strain by mechanical forces or, conversely, to produce a mechanical force when a voltage is applied across the material. Examples: Quartz, tourmaline, and Rochelle salts.

Pip. The figure presented on the oscilloscope of a radar caused by the echo from an aircraft or other reflective object. Also call BLIP.

Pitch. An angular displacement about an axis parallel to the lateral axis of an airframe.

Pitch Indicator. An instrument for indicating the existence and approximate magnitude of the angular velocity about the lateral axis of an airframe.

Plumbing. (1) Concerning missiles, the waveguide construction used in microwave systems, such as radars. (2) In power plant systems, the complex system of pipelines, fittings, and valves.

Polarization. (1) In optics, the act or process of making light or other radiation vibrate in a definite form so that the paths of the vibrations, in a plane perpendicular to the ray, are straight lines, circles, or ellipses, giving respectively, plane polarization, circular polarization, or elliptical polarization. (2) In radio, a term used in specifying the direction of the electric vector in a linearly polarized radio wave as radiated from a transmitting antenna.

Precession. A change in the orientation of the axis of a rotating body, such as a spinning projectile or gyroscope, the effect of which is to rotate this axis (axis of spin) about a line (axis of precession) perpendicular to its original direction and to the axis (axis of torque) of the moment producing that change.

PROPAGATION. Extending the action of; transmitting, carrying forward as in space or time or through a medium as the propagation of sound or light waves.

PROPAGATION, VELOCITY OF RADIO. The velocity of radio propagation, within the accuracy demanded of radar equipment, is usually taken as the velocity of light, 2.998×10^8 m/sec, or 299.8 m/μs.

PROPELLANT. Material, consisting of fuel and oxidizer, either separate or together in a mixture or compound, which, if suitably ignited, changes into a large volume of hot gases, capable of propelling a rocket or other projectile.

PULSE JET. A compressorless jet-propulsion device that produces thrust intermittently, with an operating frequency determined by the acoustic resonance of the engine. Consists of a pulsating or intermittent inlet-valve system, a combustion chamber, and a discharge nozzle. Owing to the partial vacuum created for a short time in each cycle by the pulsating nature of the combustion and exhaust, this device can take in air and produce thrust even under static conditions.

PULSE LENGTH. The time duration of the transmission of a pulse of energy, usually measured in microseconds or in the equivalent distance in yards, miles, etc., represented by the pulse signal on a radarscope.

RADAR, CONTINUOUS-WAVE. System in which a transmitter sends out a continuous flow of radio energy to the target that reradiates (scatters) the energy intercepted and returns a small fraction to a receiving antenna. Because both the transmitter and receiver are operating simultaneously and continuously, it is impractical to employ a common antenna and usually two similar structures are employed side by side and so oriented that only a small fraction of the transmitted power leaks directly into the receiver. The reflected wave is distinguished from the transmitted signal by a slight change in radio frequency. The c-w method while not so adaptable to military needs has interesting properties—(1) its ability to distinguish moving targets against a stationary reflecting background; (2) more conservative of bandwidth than pulse radar.

RADAR, PULSE. Radar in which sharp burst of radio energy, somewhat like the bursts of acoustic energy from the barrel of a machine gun, are sent out from the transmitter. When these bursts or "pulses" encounter a reflecting object, they are reflected as discrete echoes that are detected by the radar receiver during the interval between the transmitted pulses. The pulse method has the ability to measure distances and engage several targets simultaneously.

Radar, Range of. The maximum usable distance to target of a radar system; under free-space conditions, varies as the fourth power of the (1) transmitted power, (2) receiver power sensitivity, (3) target echo area; and (4) square of the antenna gain.

Radome. A contraction of the words RADAR DOME. The housing for a radar antenna, transparent to radio frequency radiation. It may include some nontransparent areas, however.

Ram Jet. A compressorless jet-propulsion device that depends for its operation on the air compression accomplished by the forward motion of the unit.

Range, Slant. The distance, in a straight line, from a gun, a point of observation, or a radar set to a target, especially an aerial target.

Range-Tracking Element. An element in a radar set which measures range and its time derivative. By means of the latter, a range gate is actuated slightly before the predicted instant of signal reception.

Raster. A system of luminescent lines traced on the phosphor of a cathode-ray tube by motion of the cathode-ray beam. The changes of brightness in the lines produce a picture as a television picture or a radar map. This word is of German origin and is used in particular in television.

Ratrace. A particular type of radar waveguide configuration that serves the same purpose as the "Magic Tee" but allows the handling of greater power.

Reactance. That component of the impedance of an electrical circuit, not owing to resistance, that opposes the flow of alternating current. The reactance is the algebraic sum of that owing to (1) inductance in the circuit with a value in ohms equal to the product of 2 π, the frequency in cycles, and the inductance in henries; and (2) capacitance in the circuit with a value in ohms equal to the reciprocal of the product of 2 π, the frequency in cycles, and the capacitance in farads.

Reactor. A device that introduces either inductive or capacitive reactance into a circuit.

Reflection Interval, Radar. The length of time required for a radar pulse to travel from the source to the target and return to the source, taking the velocity of radio propagation to be equal to the velocity of light, 2.998×10^8 m/sec. or 299.8 m/μs. Because the pulse must travel twice the distance to the target (out and back), the apparent velocities obtained are only one-half of the true velocity of the pulse. Likewise, the reflection intervals are just twice as great when target ranges are considered.

Regenerative. Feeding back. A regeneratively cooled rocket motor is one in which one of the propellants is used to cool the motor by passing through a jacket prior to combustion.

Research. A continued process of scientific investigation prior to and during development. It has for its aim the discovery of new scientific facts, techniques, and natural laws.

Resolution. In radar, the minimum separation in angle or in range between two targets that the equipment is capable of distinguishing.

Resonance. A condition in which an actual oscillation occurs at approximately the natural frequency of a system. At resonance a small input of energy produces a large amplitude of oscillation, which is limited primarily by the amount of damping present.

Resonator, Magnetostrictive. A ferromagnetic rod so designed and arranged that it can be excited magnetically into resonant vibration at one or more definite frequencies.

Rise Time. In electronics, the time required for a pulse to rise to an arbitrary fraction (usually 90 percent) of its amplitude.

Rocket. A thrust-producing system or a complete missile that derives its thrust from ejection of hot gases generated from material carried in the system, not requiring intake of air or water.

Roll. An angular displacement about an axis parallel to the longitudinal axis of an airframe.

Rudder. A hinged or movable auxiliary airfoil on an aircraft, the function of which is to impress a yawing moment on the aircraft.

Scan, Axis of. In a scanning system, the axis about which information as to the target location is collected and with reference to which target displacement is measured.

Scan, Radar. Denotes the motion of a radio-frequency beam through space in searching for a target. There are many types of scanning used that are denoted by the path described in space by a point on the radar beam, such as circular, conical, spiral, and helical.

Scanning, Electrical. A type of scanning which is accomplished electrically and without motion of the antenna.

Self-Destruction Equipment. Primacord, or some other type of explosive, in a circuit such that it may be exploded by (a) a time-delay mechanism, (b) a radio-command link, (c) an automatic trip mechanism on the roll-stabilization gyro, or other signal.

Selsyn. A General Electric Company trade name for a synchro; derived from SELf-SYNchronous. (See Synchro.)

Sensitivity. In radio-receiver usage, that minimum strength of a signal input capable of causing a desired value of signal output.

Separation. (1) The phenomenon in which the boundary layer of the flow over a body placed in a moving stream of fluid separates from the surface of the body. (2) Regarding multistage missiles, the time or place at which a burnt-out stage is discarded and the remaining missile continues on its way.

Servo Link. A power amplifier, usually mechanical, by which signals at a low power level are made to operate control surfaces requiring relatively large inputs; e. g., a relay and motor-driven actuator.

Servo System. A closed-cycle automatic-control system so designed that the output element or output quantity follows as closely as desired the input to the system. The output is caused to follow the input by the action of the servo controller upon the output element in such a way as to cause the instantaneous error, or difference, between output and input to approach zero. All servo systems are dynamic systems containing at least one feedback loop which provides an input signal proportional to the deviation of the actual output from the desired output. This property distinguishes servo systems from ordinary automatic-control systems. In general, servomechanisms exhibit the following properties: (1) Include power amplification; (2) are "error sensitive" in operation; and (3) are capable of following rapid variations of input.

Shading. The appearance of dark areas in a received television picture which sometimes covers the entire screen.

Shock Wave. An extremely thin wave, or layer of gas, generated by the relative supersonic movement of the gas stream and a body, or generated by an explosion. Free stream gas, upon passing through this wave, experiences abrupt and discontinuous changes in pressure, density, velocity, temperature, and entropy. These changes are irreversible owing to some of the pressure energy being lost to heat. Shock waves are commonly called COMPRESSIVE WAVES, and may be either normal or oblique to the gas-stream direction. The stream upon passing through a normal shock always has its velocity reduced from supersonic to subsonic. In passing through an oblique wave, the velocity is reduced but is still supersonic. In both cases the total stagnation pressure is reduced, while the density, static pressure, and free-stream temperature are increased in the gas stream.

Shoran. (1) Abbreviated name for SHORT-RANGE NAVIGATION. (2) A precision position-fixing system using a pulse transmitter and receiver and two transpondor beacons at fixed points. (See Navigation, Hyperbolic.)

Simulator. Concerning missiles, a device that solves a problem by use of components that obey the same equations as the system being studied. Frequently, an electrical analogue or rotation instead of translation is used for mechanical problems. In general, a simulator is an alternative means of determining the effects of changing each of several design parameters at much less expense than building and testing a complete missile or systems.

Skidding. Sliding sidewise away from the center of curvature when turning. It is caused by banking insufficiently and is the opposite of sideslipping.

Sonde. In telemetering, the complete airborne telemetering system in the vehicle.

Sonic, Hyper- (Hypersonic). (1) High supersonic velocities, of the order of $M=5$, or greater. (2) Velocities at which time of missile passing is of the order of the relaxation time; that is, the time for molecules to reach equilibrium after sudden change in conditions. In such a domain, gases must be treated as discrete particles rather than continuum. Measurements of relaxation times of gases are incomplete, but there are indications that Mach numbers of the order of ten must be regarded as hypersonic. Velocities that are not hypersonic at sea level may become so at high altitude, as relaxation times will be longest where densities are relatively low.

Sonic Speed. The speed of sound. In ambient air, with ratio of specific heats assumed 1.4 and the air following the gas law with temperature in degrees Rankine, the speed of sound is $33.42\sqrt{R}$ miles per hour, or $29.02\sqrt{T}$ knots; with temperature in degrees Kelvin, the speed of sound is $44.84\sqrt{T}$ miles per hour, or $38.94\sqrt{K}$ knots.

Sonic, Sub- (Subsonic). Less than the speed of sound or less than a Mach number of one.

Sonic, Super- (Supersonic). Faster than the speed of sound. When supersonic speed is attained by a moving object, no advance information in the form of advance pressure waves can be given to the advancing air, as the body is moving faster than the pressure waves emanating from the body can propagate themselves forward. As a result, shock waves are formed which move with the body, attached or unattached depending on the conditions.

Sonic, Tran- (Transonic). The intermediate speed in which the flow patterns change from subsonic flow to supersonic; i. e., from Mach numbers of about 0.8 to 1.2, or vice versa.

Spoiler. A surface which, being projected into the wind stream surrounding an airfoil, disturbs the air flow with consequent loss of lift and increase of drag.

Squib. A small pyrotechnic device which may be used to fire the igniter in a rocket or for some similar purpose. Not to be confused with a detonator which explodes.

Stability. That property of a system which causes it, when its equilibrium is disturbed, to develop forces or moments tending to restore the original condition.

Stability, Arrow. The partial derivatives of yawing and pitching moments with respect to angles of attack in yaw and pitch.

Stability, Directional. Stability with reference to disturbances about the normal axis of an aircraft; i. e., disturbances which tend to cause yawing.

Stability, Dynamic. That property of an aircraft which causes it, when its state of steady flight is disturbed, to damp the oscillations set up by the restoring forces and moments and gradually return to its original state.

Stability, Inherent. Stability of an aircraft owing solely to the disposition and arrangement of its fixed parts; i. e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of the control or the interposition of any mechanical device.

Stability, Lateral. Stability with reference to disturbances about the longitudinal axis; i. e., disturbances involving rolling or sideslipping. The term "lateral stability," is sometimes used to include directional and lateral stability, because these cannot be entirely separated in flight.

Stability, Longitudinal. Stability with reference to disturbances in the plane of symmetry; i. e., disturbances involving pitching and variation of the longitudinal and normal velocities.

Stability, Static. That property of an aircraft which causes it, when its state of steady flight is disturbed, to develop forces and moments tending to restore its original condition.

Stabilizer. Concerning aircraft, any airfoil whose primary function is to increase the stability of an aircraft. It usually refers to the fixed horizontal tail surface of an aircraft, as distinguished from the fixed vertical surface.

Steady State. The condition of a system which is essentially constant, after damping out of initial transients or fluctuations.

Sting. A rod or type of mounting attached to, and extending backward from, a model, for convenience of mounting when testing in a wind tunnel.

Strain Gage. A strain-sensitive element, that permits recording, via a bridge circuit, of displacements between selected places.

Stratosphere. The region of the upper atmosphere characterized by little or no temperature change with a change in altitude. The stratosphere is separated from the lower atmosphere, or troposphere, by the tropopause. An important constituent of the stratosphere is ozone, which plays an important role in the phenomenon of selective absorption and seems to have a significant correlation with surface weather conditions. The stratosphere is free from the clouds and connective currents of the troposphere. (See Tropopause and Troposphere.)

SYNCHRO. The universal term applied to any of the various synchronous devices as the Selsyn, Autosyn, motor torque generator, mag-slip, and Siemans. Theoretically a synchro device is treated as a salient-pole, bipolar, alternating current excited synchronous machine. The standard signal and control synchro has a two-pole, single-phase, rotor field and a Y-wound, single-phase, variable-voltage stator. The transmitter of the synchro, whose rotor is geared to, or otherwise linked with, mechanical equipment, is also called a generator, synchro generator, or Selsyn generator. The indicator, also called a motor, synchromotor, or Selsyn motor, has a rotor that is free to rotate, and is damped to prevent excessive oscillation before coming into correspondence with the rotor of the transmitter.

TARGET, RADAR. Any reflecting object of particular interest in the path of a radar beam.

TELEMETERING SYSTEM. The complete measuring, transmitting, and receiving apparatus for remotely indicating, recording, and/or integrating information.

TEMPERATURE, ABSOLUTE. Scales based upon zero degrees as the lowest temperature attainable even theoretically. Absolute zero is approximately —273.18° C, or —459.7° F.

TEMPERATURE, CENTIGRADE (C). A temperature scale divided into 100 degrees, in which the freezing point of water is regarded as 0° and the boiling point as 100°.

TEMPERATURE, KELVIN (K). An absolute temperature scale, assumed to be a measure of kinetic energy, in which (°K) = (°C) and the freezing and boiling points of water are separated by 100°. In this scale the freezing point of water is approximately 273.18° K.

TEMPERATURE, RANKIN (R). A thermometer scale based on absolute zero of the Fahrenheit scale, in which the freezing and boiling points of water are separated by 180°. The freezing point of water is approximately 492° R.

THERMISTOR. A contraction of THERMAL RESISTOR. A resistor whose value varies with temperature in a definite desired manner. Used in circuits to compensate for temperature variations in other parts or to measure temperatures, or as a nonlinear circuit element.

THERMOCOUPLE. A pair of dissimilar conductors in contact, forming a thermojunction which when heated develops a potential difference between the parts; used for measuring temperature differences.

THERMOPILE. An instrument consisting of several thermocouples so arranged as to give, when heated, a multiplied thermoelectric current; often used for detecting very slight variations in temperature. (See Detector, Infrared.)

Track in Range. To adjust the gate of a radar set so that it opens at the correct instant to accept the signal from a target of changing range from the radar.

Tracking, Automatic. The process of utilizing range data and/or angular data in such a manner as to obtain error signals which are then used to drive devices that keep the tracking system locked on a target.

Transceiver. A combination radio transmitter and receiver in a single housing with some of the electronic circuit components being used dually for transmitting and receiving.

Transducer. A device which converts the energy of one transmission system into the energy of another transmission system. A loudspeaker and a phonograph pick-up are two examples of transducers; the former changes electrical energy into acoustical energy, and the latter changes mechanical energy into electrical energy.

Transistor. A common designation for germanium triode, consisting of two fine wires imbedded at the proper spacing into a matrix of germanium, the whole exhibiting many properties of a three-element vacuum tube.

Transmission Line. A system of material boundaries forming a continuous path from one place to another and capable of directing the transmission of electromagnetic energy along this path.

Transmission Line, Matched. A transmission line is said to be matched at any plane if there is no reflected wave at that plane.

TR Box. Common abbreviation for transmit-receiver switch or tube. This switch, or tube, permits the use of a single antenna on a radar for transmission and reception. The TR box prevents the absorption of the transmitted pulse into the receiver system, thereby protecting the receiver circuit from damage, and also prevents the transmitter circuits from absorbing any appreciable fraction of the reflected echo signal. There are various types of TR boxes, or tubes, graduating to fairly complex devices in microwave systems.

Trim. (1) In electronics, denotes a small change or necessary adjustment of the tuning capacity. (2) Concerning aircraft, the attitude with respect to wind axes at which balance occurs in rectilinear flight with free controls.

Tropopause. The boundary or zone of transition between the troposphere and the stratosphere. Its height varies from 17–18 km over the Equator to 6–8 km over the poles. Its height also changes with the seasons and with the passage of cyclones and anticyclones. The temperature at the tropopause ranges from approximately −55° C above the Poles to about −75° C over the Equator.

Troposphere. The region of the atmosphere extending from the surface of the earth up to the tropopause; characterized by convective air movements and a pronounced vertical temperature gradient, in contrast to the convectionless and almost vertically isothermal stratosphere above the tropopause.

Tumbling. (1) The act performed by a two-frame free gyroscope when both frames become co-planar. Under these circumstances, the gyro wheel rotates about a diameter as well as about its polar axis, resulting in loss of control. (2) Concerning missiles and projectiles in flight, turning end-over-end about the transverse missile axis.

Turbo Jet. A jet motor whose air is supplied by a turbine-driven compressor; the turbine being activated by exhaust gases from the motor.

Turn-and-Bank Indicator. An instrument combining in one case a turn indicator and a lateral inclinometer.

Ultrasonics. The technical field pertaining to waves in a material medium, such as audible sound but of higher frequency.

Umbilical Cord. A cable fitted with a quick disconnect plug at the missile end, through which missile equipment is controlled and tested while the missile is still attached to launching equipment or parent plane.

Varistor. A special type of resistor which varies considerably with temperature; useful in making temperature measurements or in compensating circuits for other temperature effects.

Vector Quantity. A quantity that requires for description both magnitude and direction, such as displacement or velocity of a particle. (See Scalar Quantity.)

Video. The term "video" is applied to the frequency band of circuits by which visual signals are transmitted.

Warhead. The portion of a missile intended to be lethal or incapacitating; normally the warhead casing, explosive, and/or chemical or incendiary agents, etc.

Waveguide. A guide, consisting either of a metal tube or dielectric cylinder, capable of propagating electromagnetic waves through their interiors. The widths or diameters of such guides are determined by the frequency to be propagated. The metal guides may be evacuated, airfilled, or gas filled, and are generally rectangular or circular in cross section. The dielectric guides consist of solid dielectric cylinders surrounded by air.

Yaw. An angular displacement about an axis parallel to the normal axis of an aircraft.

Zoom. To climb for a short time at an angle greater than the normal climbing angle, the airplane being carried upward at the expense of kinetic energy.

APPENDIX V

SYMBOLS: ELECTRICAL, ELECTRONIC, AND PIPING

METERS.

A - AMMETER

CRO - OSCILLOSCOPE

G - GALVANOMETER

MA - MILLIAMMETER

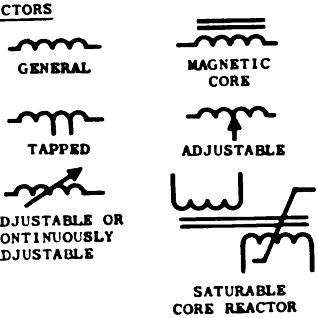
OHM - OHMMETER

V - VOLTMETER

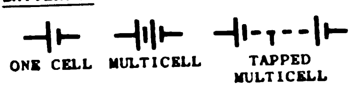
PERMANENT MAGNET

AC SOURCE

INDUCTORS

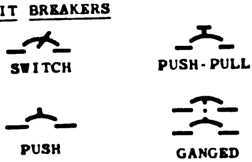


BATTERIES



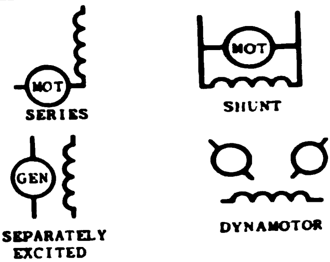
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT BREAKERS

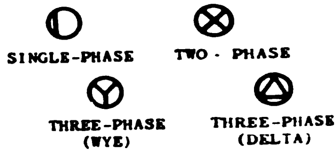


MOTORS AND GENERATORS

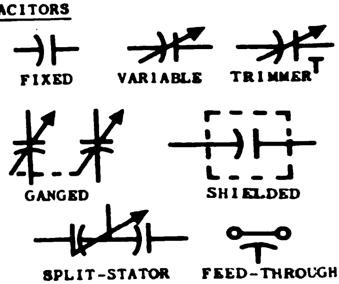
TYPES OF WINDINGS



WINDING SYMBOLS



CAPACITORS

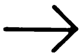


(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC. THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

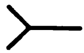
CHASSIS CONNECTION

(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

CONNECTORS



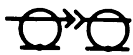
MALE
(PIN CONTACT)



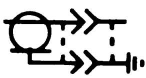
FEMALE
(SOCKET CONTACT)

ENGAGED
(PIN-TO-SOCKET)

COAXIAL
(MALE)



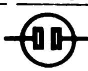
COAXIAL CONNECTORS
MATED



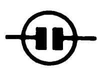
COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

POWER CONNECTORS

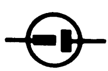


NON POLARIZED,
FEMALE CONTACTS
(2-CONDUCTOR)



NON POLARIZED,
MALE CONTACTS
(2-CONDUCTOR)

POLARIZED
FEMALE CONTACTS
(2-CONDUCTOR)



POLARIZED
MALE CONTACTS
(2 CONDUCTOR)

POLARIZED
FEMALE CONTACTS
(3-CONDUCTOR)

POLARIZED
MALE CONTACTS
(3-CONDUCTOR)

CRYSTAL UNIT

QUARTZ CRYSTAL;
PIEZOELECTRIC CRYSTAL
UNIT.

CONTACTS

SWITCH

MOMENTARY
SWITCH

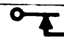
LOCKING

NONLOCKING

 OR  OR 

FOR JACK, KEY,
RELAY, ETC.

CONTACT ASSEMBLIES

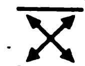


CLOSED CONTACT
(BREAK)

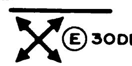
OPEN CONTACT
(MAKE)

MAKE BEFORE
BREAK

COUPLERS, DIRECTIONAL



GENERAL



E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

COUPLING

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).

COUPLING BY LOOP TO SPACE

COUPLING BY LOOP TO GUIDED TRANSMISSION PATH

LIGHT, INDICATING

 OR 

INDICATING, PILOT, SIGNALING OR SWITCHBOARD PILOT LIGHT, GENERAL.

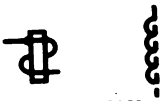
JEWELLED INDICATOR OR WARNING LIGHT.

THE LETTER L IS ADDED IN THE SYMBOL TO INDICATE LAMP.

SHIELDING

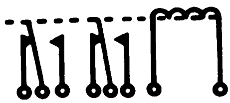
SHORT DASHES.-NORMALLY USED FOR ELECTRIC OR MAGNETIC SHIELDING

RELAYS



RELAY COIL
(DOT INDICATES INNER END OF WINDING)

RELAY WITH TRANSFER CONTACTS (SPDT)



DOUBLE POLE, DOUBLE THROW (DPDT) RELAY

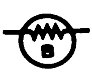
RESISTORS

GENERAL

TAPPED

VARIABLE

ADJUSTABLE



THERMAL
(BALLAST LAMP)

THERMAL
(THERMISTOR)

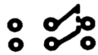
INSTRUMENT OR RELAY SHUNT

SWITCHES

GENERAL
(SINGLE THROW)

GENERAL
(DOUBLE THROW)

SWITCHES (CONT)



TWO-POLE DOUBLE-THROW SWITCH

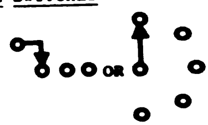
KNIFE SWITCH

PUSH BUTTON
(BREAK)

PUSH BUTTON
(MAKE)

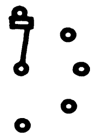
PUSH BUTTON TWO CIRCUIT

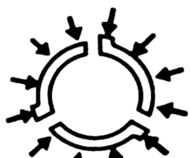
SELECTOR SWITCHES



GENERAL
ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK-BEFORE-MAKE SWITCH.

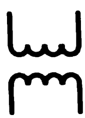
MAKE-BEFORE BREAK





WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

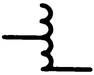
TRANSFORMERS



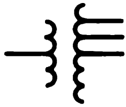
GENERAL

MAGNETIC CORE TRANSFORMER

TRANSFORMERS (CONT)



WITH TAPS, SINGLE-PHASE



AUTOTRANSFORMER

SYNCHROS

GENERAL

A LETTER COMBINATION FROM THE FOLLOWING LIST SHALL BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

- TX - TORQUE TRANSMITTER
- TDX - TORQUE DIFFERENTIAL TRANSMITTER
- CX - CONTROL TRANSMITTER
- CDX - CONTROL DIFFERENTIAL TRANSMITTER
- TR- TORQUE RECEIVER
- CT - CONTROL TRANSFORMER

TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

DIFFERENTIAL TRANSMITTER OR RECEIVER

TUBES, ELECTRON

COMPONENT TUBE SYMBOLS

DIRECTLY-HEATED (FILAMENTARY) CATHODE

INDIRECTLY-HEATED CATHODE

GRID

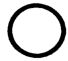
HEATER

COLD CATHODE

ANODE OR PLATE

PHOTO CATHODE

ELECTRON TUBES (CONT)



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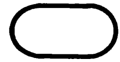
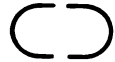


ENVELOPE (SHELL)

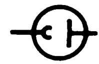
GAS FILLED ENVELOPE



SPLIT ENVELOPE

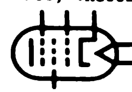
TYPICAL BUILDUP OF TUBE EXAMPLES

COLD CATHODE GAS TUBE

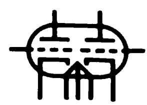


PHOTOTUBE SINGLE UNIT, VACUUM

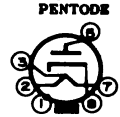
DIODE



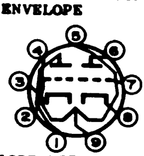
PENTODE



TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE

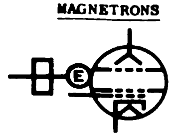


DIODE SHOWING BASE CONNECTIONS



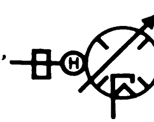
TWIN TRIODE WITH TAPPED HEATER

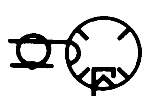
MAGNETRONS AND KLYSTRONS



REFLEX KLYSTRON, APERTURE COUPLED

TUNEABLE MAGNETRON, APERTURE COUPLED

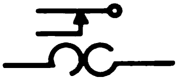




RESONANT TYPE WITH COAXIAL OUTPUT

ELEMENT, THERMAL

FLASHER; THERMAL CUTOUT



THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

FUSE

GROUND

PATH, TRANSMISSION

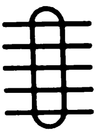
CONDUCTOR OR GROUP OF CONDUCTORS

AIR OR SPACE PATH

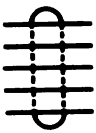
DIEL

DIELECTRIC PATH OTHER THAN AIR

CABLES

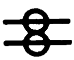


FIVE-CONDUCTOR CABLE



SHIELDED FIVE-CONDUCTOR CABLE

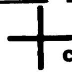
NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY



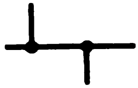
TWISTED PAIR

COAXIAL

PATH, TRANSMISSION (CONT)



CROSSING NOT CONNECTED



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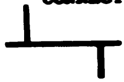
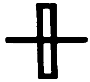


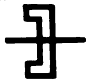
JUNCTION CONNECTED

WAVEGUIDES

CIRCULAR



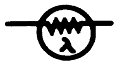
RECTANGULAR



RIDGED

PHOTOELECTRIC CELLS

ASYMMETRICAL PHOTOCONDUCIVE TRANSDUCER (RESISTIVE)



SELENIUM CELL

RECTIFIERS

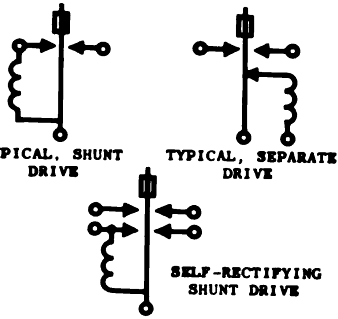
METALLIC RECTIFIER; ASYMMETRICAL VARISTOR; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER. ARROW SHOWS DIRECTION OF FORWARD (EASY) CURRENT AS INDICATED BY D. C. AMMETER.

THERMOCOUPLES

TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)

TEMPERATURE-MEASURING SEMICONDUCTOR THERMOCOUPLE

VIBRATORS



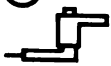
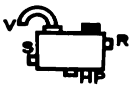
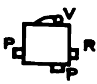
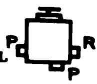
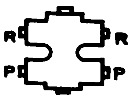
MECHANICAL SYMBOLS

TUBE AND HOSE LINES

SERVICE	RISER OR STACK	SYMBOL
ENGINE COOLANT	EC	—— EC ——
FUEL SUPPLY	F	—— F ——
LUBRICATING OIL	LO	—— LO ——
OIL BREATHER	OB	—— OB ——
PNEUMATIC	PN	—— PN ——
SELF-SEALING		
VACUUM	V	—— V ——
VENT	V	—— V ——
VENT PRESSURE	PV	—— PV ——
VENT RETURN	VR	—— VR ——
DOWN (OR CLOSE)		
EMERGENCY PRESSURE		
HOSE CONNECTION, RIGID TUBING		

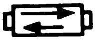
HOSE, FLEXIBLE	
RETURN	
SUPPLY FLUID, PUMP SUCTION	
SUCTION GRAVITY	
SUPPLY PRESSURE	
UP (OR OPEN)	
VENT	

HYDRAULIC AND PNEUMATIC EQUIPMENT

ACCUMULATOR	
COUPLING, SELF-SEALING	
CYLINDER, ACTUATING	
FILTER OR STRAINER	
FITTING, SWIVEL	
GAGE, PRESSURE	
PUMP, POWER DRIVEN	
RESERVOIR	
VALVE, CHECK, AUTOMATIC	
VALVE, PRESSURE REGULATING (UNLOADING) AUTOMATIC	
VALVE, PRESSURE REGULATING (UNLOADING) MANUAL	
VALVE, RELIEF	

VALVE, RESTRICTOR, BOTH WAYS

VALVE, RESTRICTOR, PARTIAL ONE-WAY



INDICATOR, QUANTITY

MOTOR, PNEUMATIC

PUMP, AIR

PUMP

FILTER, AIR

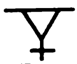
VALVE, AIR CHECK

VALVES

BACK PRESSURE

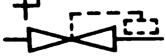
CROSS FEED

DRAIN



DUMP

FLOAT OPERATED



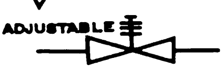
GATE

GLOBE

NEEDLE

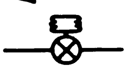
POPPET

PRESSURE REGULATOR



SOLENOID

TEMPERATURE CONTROL

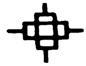


WATER REGULATOR

FITTINGS

BANJO

BULKHEAD FITTING



BUSHING

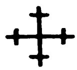
CAP

CONNECTOR, HOSE

CONNECTOR, NUT AND SLEEVE

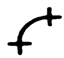
COUPLING, FEMALE

CROSS



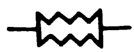
ELBOW, 45 DEGREES

ELBOW, 90 DEGREES



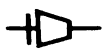
ELBOW, REDUCING

EXPANSION JOINT, BELLOWS



EXPANSION JOINT, SLIDING

FLANGE, REDUCING



NIPPLE

REDUCER, CONCENTRIC

TEE

UNION, FLANGED

UNION, SCREWED

INDEX

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